LIFE AND SCIENCE

THE SOUNDS WE HEAR

By

F R ELWELL

METHUEN & CO LTD., LONDON
36 Essex Street, Strand, W C 2

FIRST PUBLISHED 1952 BY
METHUEN & CO LTD , LONDON
36 Essex Street, Strand, W C 2

THE LIFE AND SCIENCE BOOKS

General Editor PATRICK THORNHILL

"The Water We Use," by Brian and Mary Holmes, B Sc
"The Air We Breathe," by Patrick Thornhill, B A
"Keeping Warm," by Brian and Mary Holmes, B Sc
"Light and Sight," by F R Elwell, B Sc
"The Soil We Live On," by W G Moore, B Sc
"The Current We Use," by C M Gubbin
"The Food We Eat," by Brian and Mary Holmes, B Sc
"Life and Growth," by F R Elwell, B Sc
"The Sounds We Hear," by F R Elwell, B Sc
"Work and Rest," by W G Moore, B Sc

A Leaflet for Teachers shows, among other things, which parts of an approved syllabus in elementary science are covered by each book Free on application

CATALOGUE NUMBERS
7394/U (PAPER BOARDS)
7395/U (CLOTH BOARDS)

PRINTED IN GREAT BRITAIN BY
J W ARROWSMITH LTD , QUAY STREET AND SMALL STREET, BRISTOL

CONTENTS

HOW TO USE THIS BOOK

You will not learn very much from this book if you just sit down and read it. The book is about sound, and unless you *do* the experiments on sound described in the first chapters you will not understand them. Very little apparatus is required for these experiments—and you can make all of it yourself from a few wires and bottles and so on At the ends of the chapters there are usually more experiments described, and you should also try to do all these, though they are not as important as those mentioned in the chapters themselves

There are many references in this book to music and musical instruments of various kinds. There is sure to be a piano in your school, and your teacher may sometimes be able to combine a music lesson with a science lesson Most people enjoy some form of music, singing or whistling or listening to a dance band, as well as what is often called ' serious ' music If you like one kind you are usually capable of enjoying another, and an understanding of how musical instruments work may increase your enjoyment if ever you are lucky enough to be taken to hear one of the big orchestras playing

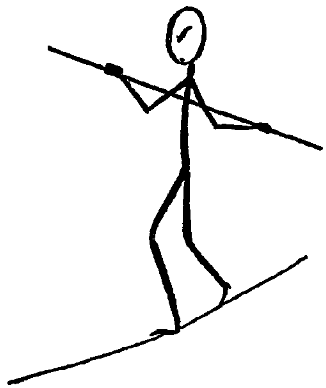
One word of warning—some of the experiments in this book are a bit on the noisy side So be careful when and where you do them You probably won't be very popular if you disturb father's Sunday afternoon nap by practising your home-made banjo just outside his window

NOTE

The film *Science and the Orchestra*, with its related film-strips and handbook, may be found very useful with this book It was made in 1950 by Realist Film Unit for the Ministry of Education for England and Wales, and is to be had from the Educational Foundation for Visual Aids, 33 Queen Anne Street, London, W 1

CHAPTER I

NOISES AND NOTES



If someone were to ask you how many senses you have I expect you would answer—"Five" And you would probably be able to name them—"Sight, hearing, taste, smell, touch" As a matter of fact you have several more senses than five There is your sense of balance, for example That is the sense that tells you whether you are walking upright or about to fall over It is something you don't think about normally, but if you have been whirling round on a fast roundabout your sense of balance sometimes does not work properly for a short time afterwards, and the result is that you feel dizzy Then there is your muscle sense. If you were handed two boxes of the same size and asked to judge which was the heavier, you would use this muscle sense You would hold each box in turn on your outstretched hand and judge which of the two seemed to put the greater strain on the muscles of your hand and arm This sense is not nearly as exact as some of your other senses, but it is a fairly reliable guide for everyday purposes There are other senses as well—your sense of temperature which tells you whether things are hot or cold, and your pain sense which is perhaps the most useful sense you have, for without it you might burn or cut yourself without knowing, and you can imagine how dangerous that might be

So next time anyone asks you how many senses you have you can say—"At least nine" And to the five that everyone knows about—sight, hearing, taste, smell, touch—you can add balance, muscle sense, temperature, and pain

All these senses are valuable to us in everyday life, but some of them are a great deal more useful than others

Many people manage quite happily without a sense of smell, they miss a few nice sensations like the smell of fresh roses or Sunday dinner, but then they are not worried by nasty smells like bad fish, so on the whole the loss of smell is not a very serious disadvantage to human beings, though it would be for some animals (Why would it matter more for a dog, do you think?) Then there is the sense of taste, people often lose that for the time being when they have a cold It is a nuisance, of course, but not an extremely serious matter But sight and hearing are different It is by means of these two senses that we learn practically everything we know about the world around us [1]

What is Sound?

This book is about our sense of hearing and the different sounds we hear, but before we begin to think about different kinds of sound we should try to answer the question "What is sound?"

Most of us are so used to taking the world of sound for granted that we hardly ever stop to think about it Sounds come to us from every side, to some of them we pay attention, others we ignore completely How many sounds can you hear now? If this book is being read aloud there is the sound of a voice, of course, but even if you are supposed to be reading it to yourself there are, I expect, at least half a dozen little sounds coming to you from your classroom or outside A rustle as someone turns a page—a cough—the creak of a desk—the sound of your own breathing—the window rattling—someone's footsteps in the corridor—voices in the street—a bird chirping—a fly buzzing Are any of these sounds happening near you at this minute? Listen very carefully How many more can you hear?

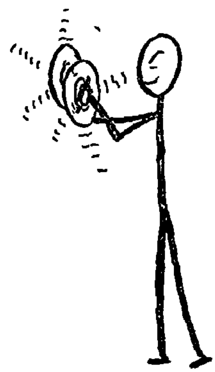
Our lives are full of sounds of one kind or another, and we are surprisingly good at telling the different ones apart Think of a door being banged—of the sound of a bicycle bell—of a chair being scraped over a floor—of the clink

[1] For more about the sense of sight see *Light and Sight*

of your knife and fork on the plate at dinner-time Those are four quite ordinary sounds, but no one could mistake one of them for any of the others First of all what *causes* the sound? Well, if you think about it for a moment you will soon realize that when a sound begins something is *moving* The door opens and closes—the clappers inside the bell swing round and hit the bell itself—the chair moves over the floor—the knife knocks against the plate

Now when a thing is moved so that it knocks against something else in this way both objects usually start to *vibrate* (that is, shake) a little The door knocks against its framework and both of them vibrate If you push the door closed with the flat of your hand you can actually feel these vibrations quite strongly Or if you touch a bicycle bell lightly with your finger as you ring it you can feel the metal vibrating Both the chair and the floor vibrate as the chair scrapes over the floor And both the knife and the plate vibrate as you clink one against the other In fact it is very difficult to move any of the solid things around us without making them vibrate a little This sort of vibration is the cause of what we call sound

How Sound is Carried

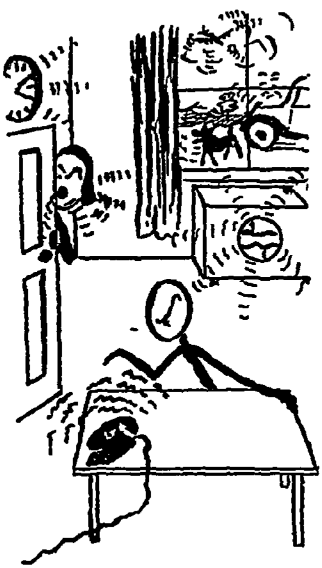


But in the world around us there are not only solid things like knives and doors and bicycle bells, there is the air itself The air fills up all the space inside the hollow of the bicycle bell, the space between the chair and the floor, the crack around the door—every single nook and cranny, they all contain air There is air all around us When we move, or when we make a door or a chair or the clapper of a bicycle bell move, then the air around starts to move as well It shakes as the door shakes, it quivers in time with the ringing bell, it trembles as the floor trembles when a chair scrapes over it

This movement of the air begins in the air immediately around the moving object But from that point the vibrations spread through the air in all directions It is something like the way ripples spread in a pond At some time

or another you must have thrown a stone into a still pond At first there is a plop, then, from the point where the stone went in, rings of ripples appear and spread out in all directions As they spread they gradually become fainter and at last they die away altogether and the surface of the pond is still once more It is very much like that with the air. If you stand in the middle of a large field and clap your hands, the air immediately around your hands begins to vibrate The vibrations of the air spread out all around like the ripples in a pond, and as they spread the sound of the clap is carried outwards, getting feebler as it goes. So sound is *caused* as a result of something moving or vibrating, and it is *carried* by the spreading vibrations of the air.

A very remarkable thing about the air is that it is able to carry any number of different sounds from different places all at once, even though the paths of these sounds may cross each other. Again it is rather like ripples in water. Here is an experiment for you to do Next time you come across a large sheet of still water throw *two* stones into it at once—and arrange your throw so that the stones fall a yard or so apart from each other. Watch the ripples very carefully. Each set begins where the stone first touched the water, and as the two sets spread out they pass right through each other; each set of ripples behaves just as though the other set of ripples were not there at all

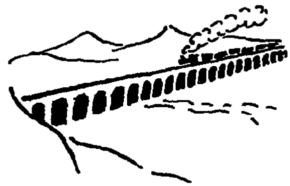


It is similar with sounds travelling through the air. A vibrating object sends out its sound waves through the air from one part of a room, and another vibrating object sends out its sound waves from another part The two sounds cross each other and travel on through the air without getting mixed up You may not hear either sound quite as distinctly as if the other were not there, but it is surprising how we can accustom our ears to hearing just the one set of sounds we want to pay attention to and ignoring the rest

Listen again to all the rustlings and other small noises in your classroom Now pick out just one of them—

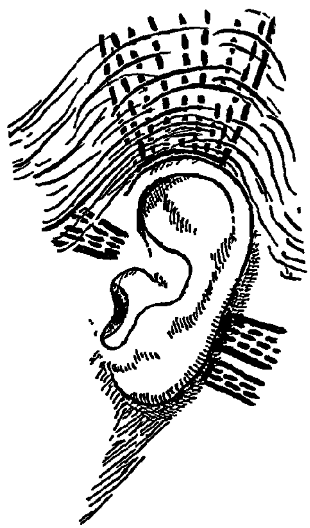
someone fidgeting in the back row perhaps—and concentrate on that You can probably find it fairly easy to ignore all the other little sounds—to cut them out altogether from your attention But if you don't try to concentrate on any one of the various little sounds you just get a general impression of slight noise

When you go home to-day listen carefully to all the outdoor noises and see how many you can distinguish You might try making a list of them, then when you return to school you can compare notes and see who has the longest list Don't forget to put in even the faint background noises such as the rustle of wind in the trees or the distant rumble of a train



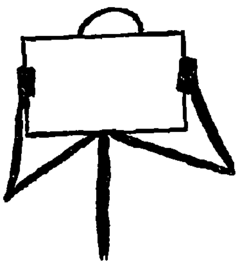
How we Hear Sounds

So far we have learnt two things about sound The first is that sound is caused as a result of something vibrating The second is that sound is carried through the air because the air itself vibrates But we are not, of course, conscious of the sensation of sound until the vibrations reach our ears



If you look at someone's ear—or at your own in a looking-glass—all you will see is a sort of pink crinkly thing attached to the outside of the head, and in the middle of it the opening of a little tunnel This much is called the outer ear, and as far as human beings are concerned it is not particularly useful With many animals the outer ear forms a sort of trumpet which *is* useful for picking up sounds Have you ever watched the way a dog cocks his ears when you call him from a distance? He turns his ear in the direction of the sound, and as he hasn't very good eyesight this helps him to judge where you are A horse, too, will prick up its ears at a sudden noise, and many other animals have trumpet-shaped ears that they can move Most human beings cannot move their ears, though we still have the little muscle corresponding to those a horse uses when it pricks its ears up But a few of us can still use these muscles Can you wiggle *your*

ears? If you can, you are an exception among human beings Even if you can wiggle your ears it isn't of much help to you in hearing The important part of hearing takes place right inside our heads



The little hole in the middle of someone's ear opens into a little tunnel—quite a short one, about an inch long At the other end of the tunnel, inside the head, is a sort of skin or membrane stretching tightly across the tunnel This membrane is the ear-drum The ear-drum plays a very important part in hearing It picks up the sounds from the air We shall have some more to say about the ear-drum in Chapter VIII, but in order to understand roughly how it works there is a very simple little experiment you can do Take a large sheet of paper—fairly stiff paper like tracing paper does very well—and stretch it tightly between your two hands Then hold it a few inches in front of your face and shout "Hallo!" as loudly as you can The air which carries the sound vibrates, and you can feel the stretched paper vibrate too

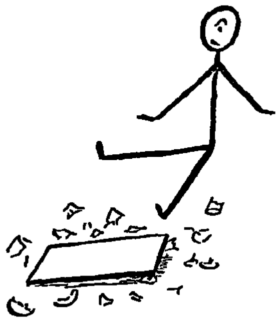
This is a very simple experiment, but it illustrates how the ear-drum works The vibrating air knocks against the paper and makes that vibrate when you hear a sound the vibrating air knocks against your ear-drum and makes *that* vibrate Without the air to carry the vibrations and without your ear-drums to pick them up you would not be able to hear sound at all.

Simple Sounds and Complex Ones

Some of the sounds we hear in everyday life are very simple ones Most of them, however, are mixtures of simple sounds, they are what we call complex Examples of the more *simple* sounds are the six pips of the Greenwich time signal, the clear note of a bird, the hum of a mosquito, a single note on the piano These are sounds that we call musical *notes* They are produced by simple regular vibrations Examples of *complex* sounds are a dog barking, a peal of thunder, the crash of broken glass, a chord played by an entire orchestra, a chord played on a piano The

first three of these could not possibly be called musical But the other two, although they are not simple notes, are probably quite pleasing to our ears, and we can call them musical sounds

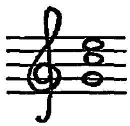
A complex sound consists of a number of simple sounds all happening at once Suppose you had a tray of glasses of different sizes and shapes If you flick one with your finger you hear a definite musical note If you flick another you get another musical note, and so on The glass, of course, vibrates when you flick it It vibrates *regularly* The vibrating glass makes the air around it vibrate, the air makes your ear-drum vibrate, and so you hear the note Now imagine the crash if you dropped the tray of glasses on the floor The sound this time would not be a musical note but a *noise* Each glass would break into dozens of pieces, and each piece of glass would vibrate, and the tray would vibrate, and the floor would vibrate, and these vibrations—dozens and dozens of them—all happening at once would combine to produce in your ears the effect of a *noise* instead of a single musical note



A *note*, then, is produced by a single set of regular vibrations

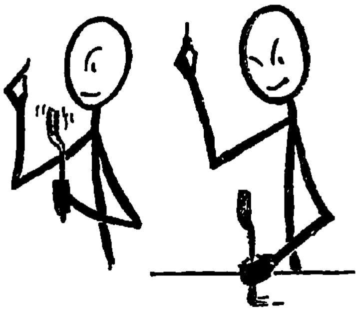
A *noise* is produced by lots of different vibrations all mixed up together

Of course if there are only a few regular vibrations happening at the same time most of us are able to pick out the separate notes quite easily Next time you have a singing lesson ask your teacher to play this chord of three notes on the school piano Can you pick out the three notes and sing them separately? Probably you can do this quite easily Although the sound is a complex one we are so used to hearing a mixture of those three notes in our music that we think of it as a collection of musical notes and not as a noise



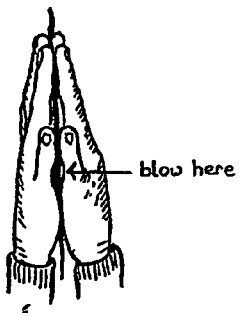
But if you press the flat of your hand down on the piano keyboard and play half a dozen notes next door to each other all at once you certainly wouldn't call *that* musical The mixture is one that we are not accustomed to in our ordinary music, it is a *noise* rather than a musical sound

Noises, then, are mixtures of notes, and in the next chapter we shall learn how one note differs from another But before you begin reading that chapter make sure you have understood all the things in this one, and do all the experiments suggested in the chapter and in ‘ More things to do ’.



More Things to Do

1 Pinch the prongs of an ordinary table fork together and let them go sharply What do you hear? Repeat the experiment but this time rest the handle end of the fork on the table Can you suggest a reason for the difference?



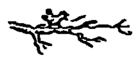
2 Can you produce a noise from a blade of grass? Stretch it tightly between your thumbs as the picture shows, and blow on the edge of it If you have allowed enough space on either side of the blade it will vibrate and you will get a very loud noise (not a very musical noise) If you haven’t a blade of grass try the experiment with a narrow strip of paper The blowing makes the paper vibrate, the paper makes the air vibrate, and so you hear a noise.

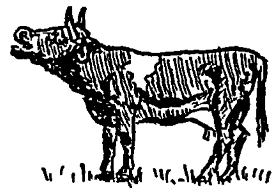
3 Can you make a glass “ ring ” by moistening your finger and stroking the glass around the rim? It takes a little practice to make a glass vibrate in this way, but if you can manage it collect eight glasses and by pouring a little water in each (you must get the exact amount by trial and error) arrange them so that they play the notes of a scale You can now play tunes on your “ musical glasses ” At one time a set of glasses was used quite seriously by certain musicians as a proper musical instrument, the composers Mozart and Beethoven, for example, wrote music intended to be played on musical glasses.

4 Musical instruments can be made to give their vibrations by hitting, by plucking, by scraping or bowing, or by blowing Make a list of all the musical instruments you can think of and write beside each the way in which the instrument is made to vibrate

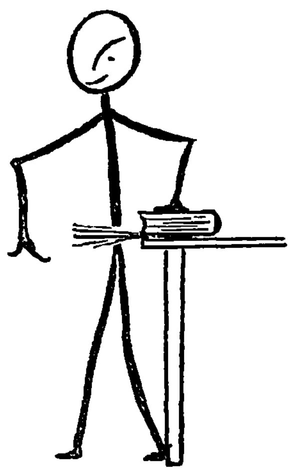
CHAPTER II

HIGH AND LOW NOTES





If you made the list suggested in the last chapter of all the noises you heard on your way home from school you probably noticed that some were high sounds and others were much lower Perhaps there was a milk-cart coming along You may have heard the horse's hooves, the jingle of its harness, a snort or two, perhaps, the noise of the wheels on the road, the squeak of the axles, the rattle of milk bottles, and so on If it was a country road you might have heard the wind rustling the trees, the note of a robin and perhaps the distant mooing of a cow If we compare just these last two sounds—the mooing cow and the singing bird—the most obvious difference between them is that one is a low or deep note, the other a high one Now a cow is a large animal It has a large voicebox and a low booming voice A robin, on the other hand, is a small animal It has a small voicebox and a high-pitched voice Generally you will notice that if a sound is made by something rather large it tends to be low in pitch, whereas if it is made by something small it tends to be higher



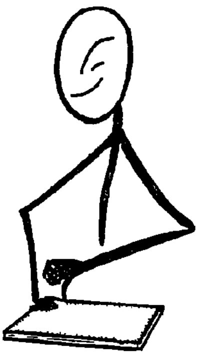
In the last chapter we learnt that sound is a result of something vibrating So whether a sound is high or low in pitch must have something to do with these vibrations Here is an experiment to do now

Notes from a Ruler

You need for this experiment a springy wooden ruler and a heavy book Arrange the ruler so that ten inches or so stick out over the edge of your desk, and hold the short end firmly in position by pressing the book down on it Now " ping " the ruler with your finger You will see the

ruler vibrating, and you will hear a very low twangy note. Now shorten the end sticking out and "ping" it again This time you will see that the vibrations are quicker and you will also hear that the note is higher Try the experiment with various lengths of the ruler sticking out You will find that the shorter the length of vibrating ruler the quicker the vibrations and the higher the note Now this is a very important rule *Slow* vibrations, *low* note, *fast* vibrations, *high* note

Notes from a Book



Here is another experiment you can do This time you need one of those exercise books with a ridged paper cover. In fact, if you have one of these books you have probably done this experiment already, only you didn't call it an experiment and somebody probably told you to "stop making that hideous noise" But this time it is part of your science lesson, so it should be all right

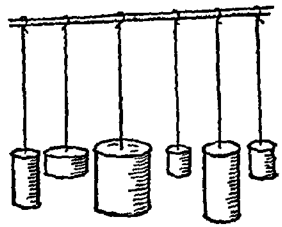
This is the experiment Just draw your fingernail slowly and evenly across the ridges of the book cover Listen carefully to the sound Every time your fingernail jumps over a ridge it gives a little shake to the air Since the ridges are evenly arranged, you produce an even series of little shakes as you draw your finger steadily over the cover If you move your finger slowly the vibrations or shakes are slow ones and you get a low note But if you move your finger quickly the vibrations follow each other more quickly, and the note has a much higher pitch

Slow vibrations, *low* note, *fast* vibrations, *high* note

Different Sizes—Different Notes

In the ruler experiment we found that the long piece of ruler vibrated more slowly than the short piece, and so produced a lower note Larger things usually vibrate more slowly than smaller ones of the same shape and made of the same material You might test that for yourselves

with tin cans of different sizes Collect as many tins as you can and make a hole in the bottom of each Thread a piece of string through the hole, knotting it on the inside of the can, and hang up the cans in a row Each can when it is hit has its own particular rate of vibration and gives its own particular note If you hit the cans in turn with a piece of metal you can find which gives the lowest note, and arrange them in ascending order Other things being equal, you will find that the larger the can the lower the note it produces

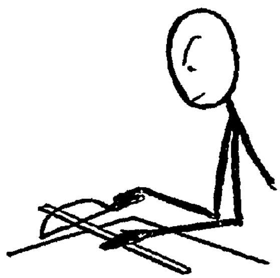


You can think out similar experiments for yourself with plates and cups and jugs of different sizes (But don't forget that the note does not only depend on the *size* of the vibrating object, *it depends on its* *shape* *and the* *stuff it is made of* as well) Quite a lot of musical instruments work on this principle a number of objects each having its own particular rate of vibration, and each producing its own particular note, are arranged in order, to give the notes of a scale

If we want to make a musical instrument of this sort it is just as well to choose pieces of the same material If you are handy with a few simple tools you can quite easily make a model xylophone

A Xylophone

A real xylophone has a number of wooden bars of different lengths supported side by side on a stand Each bar has its own particular rate of vibration when it is hit with a little hammer, the shorter the bar the faster it vibrates and the higher the note it produces For your model xylophone you may find it easier to use bars of brass or some other metal You can buy narrow brass strips at a shop where they sell curtain-rails, and it is quite easy to cut brass with a small hacksaw

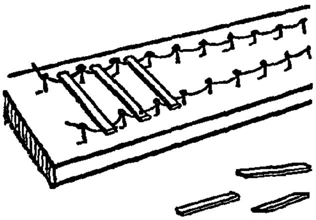


Provided that the metal is of even thickness all the way along here are the approximate lengths you need to give you the notes of a musical scale You can always tune the notes a little higher by filing off a little metal from one end,

or making them a little lower by sticking on a small dab of solder

$\underline{4''}$ $3\frac{3}{4}''$ $\underline{3\frac{9}{16}''}$ $3\frac{3}{8}''$ $\underline{3\frac{3}{16}''}$ $\underline{3''}$ $2\frac{13}{16}''$ $\underline{2\frac{11}{16}''}$ $2\frac{1}{2}''$ $\underline{2\frac{3}{8}''}$ $2\frac{1}{4}''$ $\underline{2\frac{1}{8}''}$ $2''$

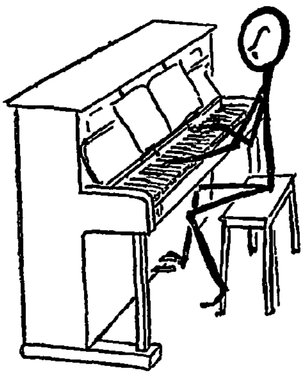
The ones underlined correspond to the notes of an ordinary scale, the others give the sharps and flats



When you have cut your pieces of metal the right length put a dab of black paint on the sharps and flats, and then arrange all thirteen pieces in their order of length You now need to mount them on a stand A simple stand can be made from a piece of wood with two rows of nails standing up from it, each nail about twice the distance from its neighbour as the width of your metal strips A piece of thin cord is tied tightly around the head of each nail so that it makes a series of loops along each row The two rows of nails should be closer together at one end than the other so that they are the right distance apart to support the pieces of metal in the loops The diagram shows you how to do this You can play tunes on it by hitting the centre of the notes with the end of a pencil around which a small piece of leather has been glued

The Piano

Quite a number of musical instruments work, like the xylophone, on the principle of a separate part for each note Each part has its own particular rate of vibration and gives its own particular note The piano is an instrument that works in this way. When the front is taken off you will see at the back of the piano a number of stretched wires, some thick and long, others thinner and shorter When you press down the keys on the keyboard of the piano, little hammers inside jump up and hit the wires The wires vibrate, and each gives out its own particular note corresponding to the rate of vibration.

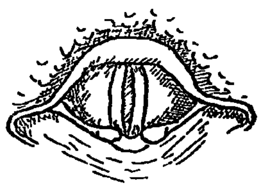


If you play a single note on the piano you will notice that so long as you keep the key down it goes on sounding for a little time after the string has been hit But when you release the key the note stops sounding It would be a very unpleasant noise if all the notes went on sounding

when you were playing a quick run or a scale So inside the piano there is a little piece of felt belonging to each key so that when the key is released the felt touches the wire and stops it vibrating But when the loud pedal is pressed down the felts are kept away from the wires, so then the wires continue to vibrate after each key has been released, and if you keep your foot on the loud pedal the whole time you are playing you get a most unpleasant jangling sound Learning to use the loud pedal correctly is a very important part of piano playing, as those of you who learn the piano have probably discovered

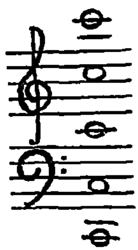
The Human Voice and its Range

Not all musical instruments work by having a series of separate pieces each vibrating to give one fixed note only There is one musical instrument we all possess, the voicebox, which is capable of producing a whole range of different notes from a very few parts How is it done? All you can feel of your voicebox from the outside is the rather knobbly Adam's apple in your throat The Adam's apple, or voicebox, is part of your breathing tube; every time you breathe in or out air passes through it Inside the voicebox there are two membranes stretched across with a space in the middle These membranes are called the vocal cords When they are stretched tightly and air blows through the space between them, the vocal cords vibrate, and this produces the sound The tighter you stretch your vocal cords the faster they vibrate and the higher the note you produce If you scream the note is very high indeed—that means that your vocal cords must be stretched very tightly You can show how stretching the vocal cords makes a higher note by twanging a rubber band between your fingers The tighter you stretch the band the higher the note it produces If you stretch it too hard it gives way altogether Screaming, and trying to sing notes that are too high for you, are bad for your voice as the vocal cords are stretched too much and may become strained or damaged



The range of a man's voice is lower than a woman's because his voicebox, and the vocal cords inside it, are bigger to begin with, and vibrate more slowly The slower the vibrations the lower the note Boys and girls have shriller voices than older people as their voiceboxes are smaller, and as they are much the same size in both girls and boys it is very difficult to tell voices of girls and boys apart But as a boy gets into his teens his rate of growth suddenly increases very much, his voicebox also grows quickly, and his voice "breaks" A girl's voice also deepens as she gets older, but it gets deeper more gradually and a woman's voice very seldom gets as deep as a man's

The usual range of notes for a human voice is about a couple of octaves The lowest note that a man with a deep bass voice can normally sing has a rate of round about 66 vibrations a second. We usually speak of this as a *frequency* of 66—the word "frequency" simply means rate of vibration. This particular frequency corresponds to the note C two octaves below middle C on a piano. So the highest note the bass voice can comfortably reach is somewhere about middle C, which has a frequency of 262 A woman with a high soprano voice can manage a note with a frequency of round about 1,048—that is the C two octaves above middle C on the piano. Most of us cannot manage notes quite as low or as high as these



When we are singing we produce single notes which are more or less constant in pitch; we can say that each note has a definite frequency—that is, it has a definite and regular rate of vibration People who sing out of tune cannot keep their notes at the right pitch; they may sing sharp or flat, or their voices may wobble Even some people who think they are good singers have a rather unpleasant wobble or *vibrato* when they sing This means that the rate of vibration of the note, instead of staying the same, gets alternately faster and slower As a matter of fact, very few people can sing a perfectly true note Most of us, however, have not sensitive enough ears to detect whether an unaccompanied singing voice is very

slightly sharp or flat, and a very slight *vibrato* is quite usual among really good singers

In crooning the singer deliberately does *not* keep a constant pitch to each note He often begins a note several tones below its correct pitch and gradually increases the frequency of the note so that he wanders up to it with a sort of slur

When we are speaking, as distinct from singing, we are not usually keeping the rate of vibration of our vocal cords constant The pitch of our voice varies enormously, not only from word to word, but actually within each word Try saying the word " Hallo " aloud and listen to it very carefully Repeat it rather more slowly Now " hum " it Do you hear how the pitch varies?

The sound we make in talking does not only depend on the frequency of the notes produced by the vocal cords, it is modified very much by the air cavities in the mouth and nose, and the relative positions of the tongue, the teeth and the lips also help to modify the sounds so that we can produce combinations of notes and noises that other people recognize as words

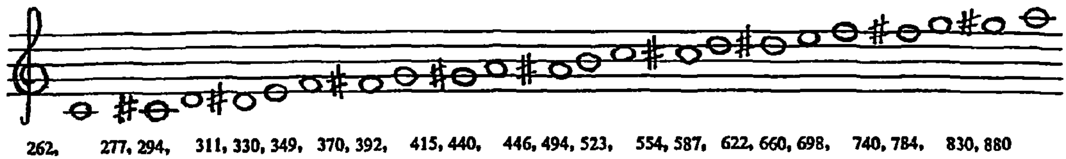
More Things to Do

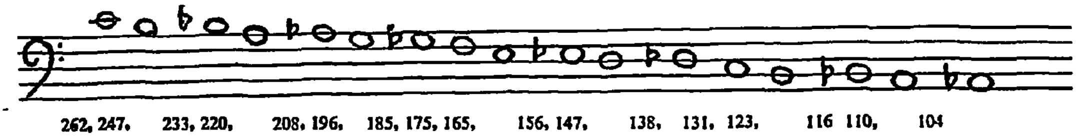
1 Some pocket combs are tapered towards one end If you have a comb of this kind run your finger slowly along the ends of the teeth and listen to the changing notes What happens as you move your finger from the end with the longer teeth to the end with the shorter ones?

2 Collect a number of rather long pins and stick them in a row into the bottom of an upturned small box, push them into the wood so that various lengths stick out and you can " ping " them to produce the notes of a scale Which pins produce the higher notes?

3 Some families have stored away in a lumber-room an old-fashioned musical box If you have one of these, even if it is broken, try to find out how it works and how many different notes it can produce

4 Musical instruments vary slightly in the way they are tuned, the note we call middle C on a very old church organ may not have exactly the same pitch as the middle C on a modern piano This





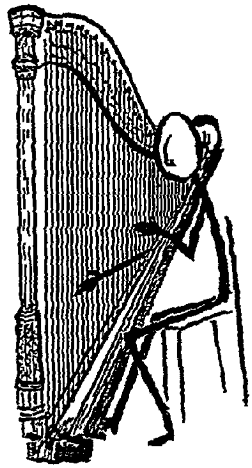
does not matter very much for some purposes, but it would be confusing if the instruments of an orchestra all chose different frequencies for middle C Musicians have agreed that for broadcasting at any rate, the standard frequency for middle C shall be 262 Here are the frequencies for some of the notes above and below middle C

With the help of a piano find the highest and lowest notes you can comfortably sing (do not strain your voice doing this) and make a note of their frequencies

CHAPTER III

NOTES FROM STRINGS

Have you ever seen a full orchestra playing? If you have never seen a real one you have probably seen one on a film at some time There may be anything up to a hundred players in it, or even more, and each one plays a separate musical instrument Some of these instruments—the drums, for example—are played by hitting Some of them—the brass instruments such as the trombone, and the woodwind instruments such as the flute—are played by blowing The remainder are the stringed instruments, and they are played either by plucking or by bowing the strings



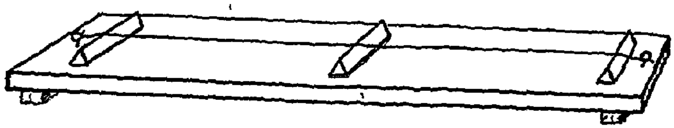
There are two different kinds of stringed instrument in a full orchestra The first kind works on much the same principle as the piano—you remember that in the piano there are wires of different lengths corresponding to the different notes You sometimes hear a piano, or its relative the harpsichord, played with an orchestra, though most orchestral music does not include a part for one of these instruments But there is often a part for another instrument with a great many strings—the harp There are forty-six strings to the harp and each string gives its own particular note when it is plucked The short strings give the higher notes, the longer strings the lower notes

In the main stringed instruments of the orchestra—the violin, the viola, the violoncello, and the double bass—there are only four strings (sometimes five in the double bass) Yet a violinist can produce a very great number of notes from his instrument Although each of the four strings has its own particular note when the full length is plucked or bowed, it can also give a whole range of higher notes

Length and Pitch

In order to understand how this happens you need to make a very simple apparatus which is really a rough model of a violin

You need a length of piano wire or a violin string, two eyelet screws and a long flat piece of wood with two small pieces nailed across the ends to act as feet Or if you prefer it you can use an upturned sugar box or the upturned drawer from a table for the wooden base You also need a short length of hard wood with triangular cross-section to make three little bridges (If you cannot get this very easily you must invent some other form of bridge, the important thing is that its base should be firm and the top as fine as possible)



Glue two of the bridges to the ends of the wood and stretch the string tightly across them, fastening the ends to the eyelet screws as shown in the diagram The string can be tightened by turning the screws At the bottom of the third bridge stick a thin piece of card This will make it very slightly higher than the end bridges

If you pluck the wire you can see it vibrate and you can hear the note it gives out Now push the movable bridge under the wire and pluck one section of the wire on its own Does it give a higher or lower note than the whole wire? Try moving the bridge along to make a different length of wire vibrate each time You will discover that as you make the wire shorter the note gets higher

Now this is exactly what a violinist does when he plays a violin He does not push a movable bridge under the string of course, but he shortens the length of the vibrating part by pressing his finger on it As he makes the length shorter and shorter so the note gets higher

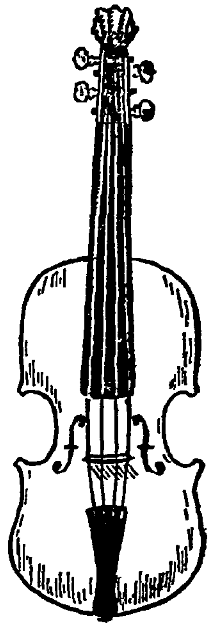
A violinist sometimes makes the string sound by plucking it with his finger, but usually he sets it into vibration by drawing the bow across it The hairs of the bow are rubbed with resin and are sticky They seize the string and pull it slightly to one side, stretching it a little until the tension becomes too great and it slips back again This is repeated again and again very rapidly, and the effect is that the whole string is thrown into vibration When the whole string is vibrating you hear what is known as the note of the open string As the violinist shortens the string with his finger the note gets higher and higher

On your model measure the length of the string between the fixed bridges and then place the movable bridge at a point exactly half-way between them How does the note you get from half the string compare with the note from the whole string?

Tension and Pitch

If you look at a violin—or a picture of one—you will see that there are four strings on it, and the parts of them that vibrate are all exactly the same length Yet when the

violinist plays these open strings in turn you hear four quite different notes—the G below middle C, the D just above, the A above that and the E above that ′ The pitch of a note, then, does not depend wholly on the length of string that is vibrating



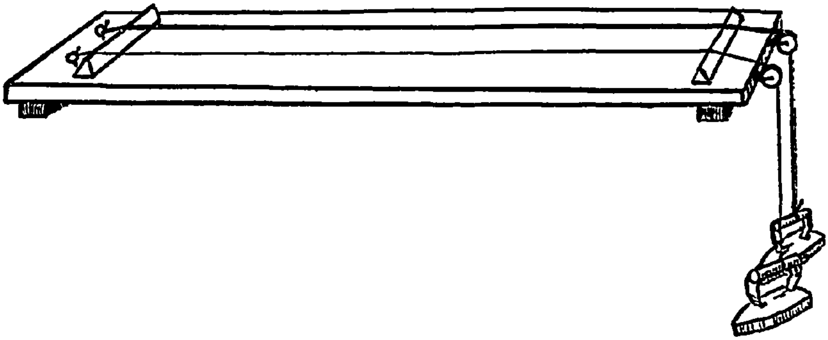
You can test this quite easily for yourself with the piece of apparatus you used in the last experiment Pluck the string, and then tighten it by turning the eyelet screw one end, plucking as you turn What happens to the pitch of the note as the string gets tighter?

The violinist tunes his four strings by means of the four screws at the end of the finger board The tension or tightness of the strings has to be exactly right for the four notes G, D, A and E to be exactly in tune The tension in the strings of a violin alters very easily—even the temperature of a warm room will make a considerable difference For this reason you will hear the members of an orchestra tuning their instruments not only at the beginning of a concert but between the items as well

Another Experiment to Try

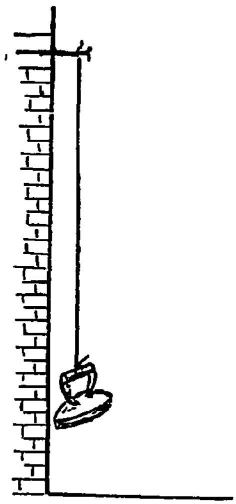
Although the four strings of a violin differ from each other in their tightness or tension, the difference in the notes they produce does not only depend on this If you look at the four strings of a violin you can see that they are of different thicknesses, and probably made of different material The G string, for example, is made of rather thick gut wound round and round with very fine steel wire The E string on the other hand is very thin and may be made either of fine gut or of a single strand of very thin steel wire The G string is the heaviest of the four strings and it gives the lowest note The E string is the lightest and gives the highest note The other two are in between

You can adapt your piece of apparatus to show this difference too You will need this time two small pulleys and two equal, rather heavy, weights Collect wires of different thickness Fasten two of them to eyelet screws at one end of the wooden base, let them pass over the two fixed bridges, and then over the pulleys (you can see



from the diagram how to fix these). Arrange the apparatus on a table so that the pulleys project over the edge, then fix your weights one on the free end of each piece of wire so that they hang freely. As the weights are equal they will be pulling equally on the two pieces of wire—in other words the tension in the two pieces will be the same Pluck each wire and find out which gives the higher note You can compare all your lengths of wire in this way and arrange them in order

We have now found that the note given by a vibrating string depends on three things The first is the *length* of the vibrating part, the shorter the string the faster the vibrations and the higher the note The second is its *tension*, the tighter the string the faster the vibrations and the higher the note The third is its *weight*, the lighter the string the faster the vibrations and the higher the note



Increasing the Volume

If you hang a violin string from a nail on the wall, attach a weight to the free end in order to make it taut, and then pluck it with your finger, you will find that you get very little sound In a violin or a piano or any other stringed instrument the main volume of the sound you hear is coming not from the vibrating string but from the body of the instrument, which acts as a sounding-board

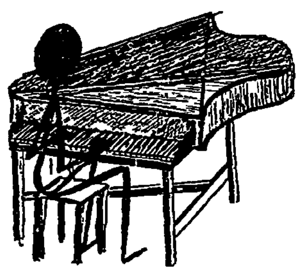
If you strike the prongs of a tuning-fork you can see that they are vibrating but very little sound is heard until you press the stem of the fork on a table or some other flat surface which can also vibrate The table vibrates in time with the fork and as it has a large surface a great volume of air is also set in vibration and the sound you hear is a loud one

All stringed instruments depend for their effect on sounding-boards In the piano, for example, the back of the instrument acts as the main sounding-board The frame of a modern piano is made of steel, for the combined tension in the strings is so high that it may be equal to thirty tons in weight The strings are stretched over two bridges; one carried by the steel frame and the other attached to the sounding-board When the wires are made to vibrate, this second bridge and the sounding-board vibrate at the same rate, and so a much greater volume of sound is heard than if each string simply vibrated on its own

In a violin all the different parts vibrate when the strings vibrate, the " tone " of a violin depends on the structure of these various parts, and we shall learn more about this in Chapter V

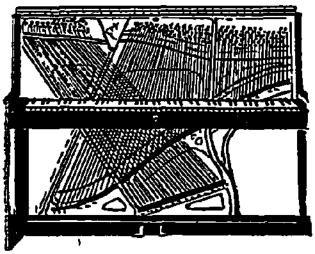
More about the Piano

As the piano is perhaps the commonest of all stringed instruments and one of the most interesting you might like to know a little more about it Its early ancestors were the clavichord, the spinet and the harpsichord Perhaps you can find some pictures of these instruments in old books, or if there is a museum near you you may be able to see the actual instruments there The harpsichord is still sometimes played at concerts but the other two instruments are seldom heard nowadays



In the harpsichord the strings were plucked when the keys were pressed, no variation in loudness or the quality of the notes was possible Just about 250 years ago a harpsichord maker named Cristofori invented a kind of

harpsichord in which the strings were struck by hammers instead of being plucked when the keys were pressed down, and which was able to give both soft and loud notes. Now the Italian words for soft and loud are *piano* and *forte*, so the new instrument came to be called the *pianoforte* We usually call it the *piano* for short Cristofori's piano only had a range of four or four and a half octaves Since his time the range has increased and is now more than seven octaves The strings of a piano are stretched at such a high tension that an immense strain is put on the framework In Cristofori's day the frame was made of wood It was the introduction of the much stronger modern steel frame that enabled the number of strings to be increased



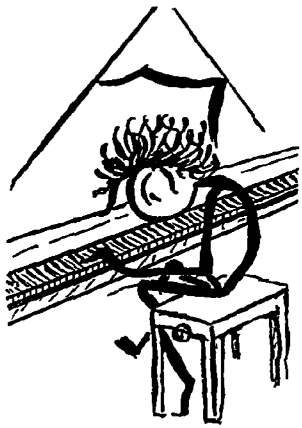
Although there are eighty-eight notes on the keyboard of a modern piano the exact number of strings varies, depending on the make The very lowest notes have only a single wire each, but the higher notes have a set of two or three strings The length of the strings may vary from over six feet for the lowest notes in the bass to only two inches for the highest ones in the treble

The bass strings are wound round with thinner wire to increase the weight and so make the rate of vibration slower, the frequency of the lowest note in the bass is only 27, that of the highest in the treble 4,096

The piano has one great drawback as a musical instrument In the violin the player can sustain a note as long as he likes, making it louder in the middle or softer just as he pleases In the piano each note is at its loudest just after the hammer hits the string After that it is bound to get softer and softer As we are so used to this effect when a piano is being played we do not usually think of it as a drawback, but a far greater range of tone would be possible if the pianist were able to control the loudness of each note while it was actually sounding.

Many people who play the piano have an idea that there is something almost magical about what they call ' touch ' You will see them waggling their fingers backwards and forwards as they press on the keys, or perhaps stroking

them lovingly It is difficult to understand why they do this Once the key has been depressed and the hammer has hit the string nothing the player does to the key can make any difference to the sound, except how long he keeps it down The only thing the pianist can vary in his ' touch ' is the force with which he makes the hammers strike the wires The harder he hits a key the harder the hammer inside the piano hits the string and the louder the note A skilful pianist has, of course, very great control over the force with which he strikes the keys, and this control, together with slight variations in timing, are responsible for the quality of his playing



Some musicians feel very annoyed when they are told that rocking their fingers on the keys cannot possibly affect a note that has already been played In order to prove this a world-famous pianist was asked to play a single note on the piano, and immediately after the same note was struck with equal force by allowing a weight to fall on the key The results were recorded, and no matter how often the experiment was repeated no one could tell any difference between the famous pianist's ' touch ' and that of the mechanical weight

More Things to Do

1 If your teacher will allow it have another look inside your school piano See if you can tell which of the notes have single strings, which are in sets of two, and which in sets of three You may also be allowed to watch next time the piano-tuner calls He may be willing to remove the hammers from the piano and show you how the strings are arranged on the frame Ask him to explain to you how the loud pedal and soft pedal work

2 If you know anyone who plays a banjo or mandoline ask them to show you how the instrument is tuned and how it is played In some stringed instruments of this kind the notes are plucked with the fingers, in others a small piece of metal is used

3 If you are fairly ingenious try making a model banjo from a small box with a strip of wood attached to it for the finger-board You will have to buy the wires from a music shop, but you could use ordinary eyelet screws as pegs for tuning your banjo

CHAPTER IV

NOTES FROM PIPES

In all the ways of producing sound we have so far mentioned we have been considering the vibration of something solid—a violin string, glasses, pieces of metal or wood, and so on. In all the wind instruments of the orchestra the notes do not come from the vibration of solid objects but by the vibration of columns of air of different lengths.

Everyone has absentmindedly at some time or other blown across the end of a fountain-pen top, or even a roll of paper, and listened to the note it made. The note in this case is given not by the fountain-pen top or the roll of paper, but by the air inside. How does this happen?

If you can get a short length of metal tubing—gas piping or something of the kind will do quite well—place your hand across one end and blow gently over the other. You will hear a note, not much of a note, perhaps, but something definitely recognizable as a note of a definite pitch. Forget the tube itself for the moment, and just think about the air inside the tube. Air is elastic—you can squash it up into a smaller space and it will expand again when you release it.[1] Imagine the column of air inside the tube being squashed in just a little way. Now imagine it expanding again—it can expand in only one direction, the end of the tube that is open to the air. If you imagine this squashing up and expanding taking place over and over again, very rapidly and regularly, it is the same thing as saying that the whole column of air is *vibrating*—getting shorter, longer, shorter, longer over and over again. As it vibrates, the end of the air column at the open end of the tube will be giving a regular series of little pushes to the outside air, so *this* will vibrate too, and when the vibrating

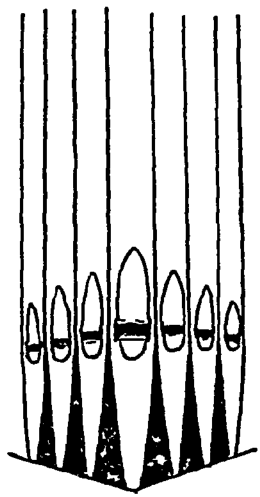
[1] See *The Air We Breathe*, Chapter X.

air knocks on your ear-drums you hear the note The whole thing is started by the little puffs of air at the top of the tube when you blow across it

You get the same thing happening even if the air column is not straight and regular all the way down Try blowing across the top of an empty medicine bottle You should be able to produce quite a good musical note

An Imitation Organ

If you collect a number of bottles of different sizes and blow across the top of each in turn you will find that they do not all give the same note You will probably expect this Those with the longer columns of air give the lower notes, those with the shorter columns, higher notes Add some water, a little at a time, to the medicine bottle, blowing across the top each time The more water you add, the less air there is to vibrate and the higher the note



Collect a dozen or so medicine bottles of the same size Pour a little water into each and adjust the amounts so that you get from the bottles the notes of a musical scale Bind the bottles firmly together with sticking plaster round the bottom and sides, and there is your imitation organ With a little practice you can play simple tunes on it

A big church organ works on the same principle There is a separate pipe for each note, and when air is blown across the end of the pipe the column of air inside the pipe vibrates and gives its own definite note The longer the pipe the lower the note The longest pipe in a church organ may be thirty feet long, about as high as an ordinary house It gives a very low note of frequency less than 20 The shortest pipe in many organs is only three-quarters of an inch long, it gives a high note of a frequency more than 8,000

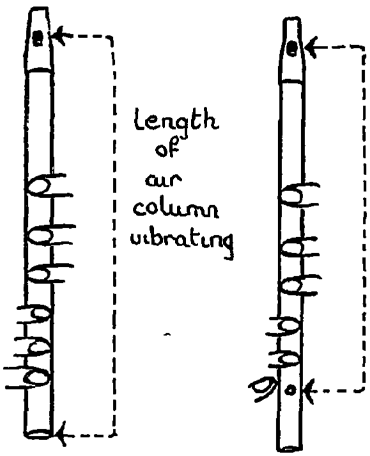
The Penny Whistle

Not many wind instruments work on the principle of having a separate pipe for each note, it would be far too

cumbersome for a portable instrument There is usually some means of making a single column of air inside the instrument either longer or shorter This alters the rate at which it vibrates and so the player can get a succession of notes, some high, some lower

The simplest way of varying the length of the air column is that used in the little instrument once known as the penny whistle, or tin whistle It was made of metal, and you could buy it for a penny Nowadays a similar instrument costs at least a shilling and it is made of plastic instead of tin But the way it works is exactly the same as in the old penny whistle (Recorders and home-made bamboo pipes work in the same way—see page 28)

When you blow into the mouthpiece of this sort of whistle your breath impinges on a sharp edge and this breaks up the steady stream of air into a succession of little puffs The puffs set the air column inside the whistle vibrating, and according to the length of the air column so you get a high or a low note

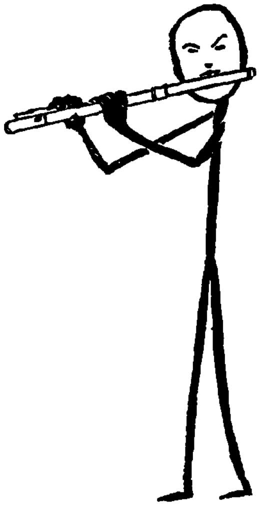


The tin whistle has a number of holes along it which can be covered with the player's fingers When all the holes are covered the whole column of air vibrates But when the lowest hole is opened this acts as though it were the open end of the tube, so the length of the air column actually vibrating is shorter, and the note correspondingly higher When the next hole is uncovered the length of the air column vibrating becomes shorter still, and the note again higher And so it goes on The positions of the holes are carefully chosen so that the different lengths of vibrating air give the notes of a scale With a little practice anyone can play tunes on a whistle of this kind

Wind Instruments of the Orchestra

A much more difficult instrument to play, although the principle is much the same as in the penny whistle, is the flute Here there is no mouthpiece to direct the player's breath against the sharp edge He has to do the directing himself—by blowing across a hole in the side of the flute

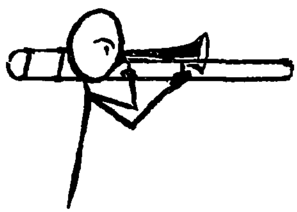
It takes quite a lot of practice before a beginner can get any sort of note from a flute, and still more before he can play tunes on his instrument



In the flute, the piccolo, the oboe, the clarinet, the saxophone, the bassoon, and several other similar instruments, the player alters the length of the vibrating air column in exactly the same way as in the humble penny whistle—by opening or closing holes in the sides of the tube and so making the length of the vibrating column of air shorter or longer In some cases the holes are closed with the fingers, in others with small keys The method by which the air column is set into vibration differs among these different instruments, though in all of them the vibrations are started by the player's breath

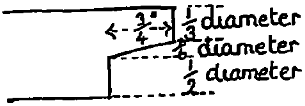
Overtones

Besides the instruments already mentioned there is an important group of wind instruments in an orchestra made of metal—usually brass This group includes trumpets, trombones, horns and so on In many of the brass instruments the tube, instead of being in a long straight piece, is curled round several or many times In the French horn there are extra loops which can be added to the total length of the vibrating air column when the player presses the appropriate valves In the trombone the length of the vibrating air column can be altered by sliding a long loop of the tube in and out As the tube is made longer or shorter so the note it produces can get lower or higher



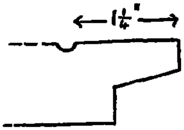
But these are not the only ways in which such an instrument can be made to vary its note If you blow the lowest note on a tin whistle very softly, then blow it harder, the note suddenly jumps up an octave You have produced what is known as an *overtone* or *harmonic* In the case of a pipe like a tin whistle, open to the air at both ends, the air column may vibrate as a whole, this gives the main or *fundamental* note Or, if the air is more violently agitated, it may vibrate in two separate halves This gives the first

overtone—in this case a note an octave higher than the fundamental (You may remember in your experiment with stretched strings that when half the string vibrated it gave a note an octave higher than when the complete string vibrated) If you blow still harder the pitch of the note shoots up still more, the air column is now vibrating in thirds instead of halves. The harder you blow the higher the pitch of the note, for the air column then vibrates in quarters, fifths, and so on

1


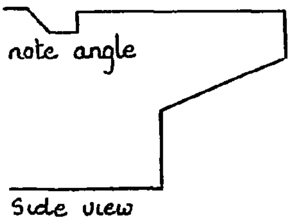
In a tin whistle this kind of over-blowing, as it is called, produces most unmusical squeaks, but in wind instruments such as the French horn where the tube is very long and the fundamental is very low, nearly all the notes are produced by deliberate over-blowing

2

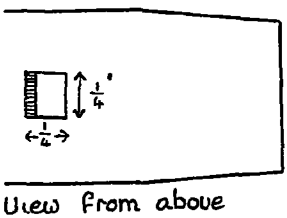

3


Something to Make

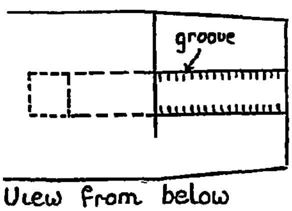
Some schools have their own recorder bands—a recorder is an instrument something like a tin whistle, but with a much more mellow tone You can get recorders in several sizes—the larger ones, of course, can play lower notes than the smaller ones Good recorders, however, are rather expensive to buy, so some schools make their own pipes out of bamboo. A bamboo pipe is not very difficult to make if you are handy with a penknife, but if a number of people in your school all make bamboo pipes I should warn you that it is very hard to get them all exactly in tune, and if they are played together the result is usually more fun for the players than for the audience But don't let that put you off

4


To make a bamboo pipe you need a straight length of hollow bamboo cane eleven inches long and about an inch across The first thing to do is to shape the mouthpiece end Diagram 1 shows you how to do this Three-quarters of an inch from one end make a scratch just half-way round the tube Cut through this, then extend the cut slightly upwards to the end of the tube Diagram 2 shows you the cut mouthpiece from one end

5


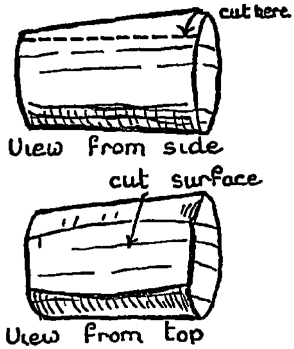
Now bore a small round hole in the top of the tube $1\frac{1}{4}$ inches from the same end (Diagram 3) Enlarge this hole to make a little square window $\frac{1}{4}$ inch across, but as you cut it shape the edge furthest from the mouthpiece end so that the side slants at an angle of 45 degrees as shown in Diagram 4 Diagram 5 shows you the appearance of the window from above

6


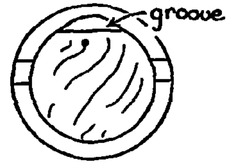
From the square window to the end of the mouthpiece, inside the

pipe, hollow out a shallow groove This will form the channel through which your breath will impinge on the sharp edge of the window Diagram 6 shows you the mouthpiece end from below with the position of the window in the top and part of the groove as dotted lines

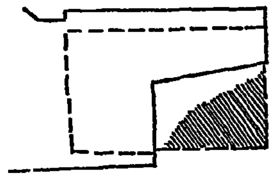
The next bit is the trickiest You have to find a cork that will exactly fit the mouthpiece and extend as far as the beginning of the window From the side of the cork that will come next to the groove cut a very thin slice (7) When it is in position there should be a space of about $\frac{1}{16}$ inch between the cut top of the cork and the roof of the groove Unless this space is exactly right the note you get when you blow along the groove to the slanting edge of the window will be thin or husky or you may not even get a note at all You may spoil several corks before you manage to cut one exactly right, but it is worth taking some trouble with this part of the work Diagram 8 shows you the end of the pipe with the cork in position, and Diagram 9 a view from the side When your cork is exactly right you can trim away the shaded part to make it comfortable to hold between your lips



7



8

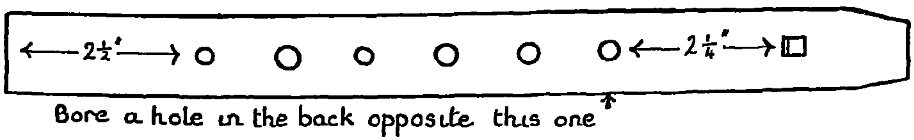


9

Now comes the interesting part of boring the finger-holes The first one is $2\frac{3}{4}$ inches from the window, and the last one $2\frac{1}{2}$ inches from the end Mark the positions of these two first, then mark out the positions of the other four so that you have six finger-holes in all along the top of the pipe Bore the holes all very small to begin with, then gradually enlarge them, beginning at the far end and tuning each against the lowest note of the pipe as you go You will find that some holes need to be slightly larger than the others A round rat's-tail file is useful in smoothing the edges of the holes

Bore a seventh hole in the back of the pipe immediately opposite the hole next to the window The thumb of your left hand covers this, and the first three fingers of both hands cover the holes on top

All you now need to do is to practise getting the notes of the scale correctly, and then you are all set for playing simple tunes on your pipe With a little more practice you will be able to manage sharps and flats by half-covering some of the holes, and over-blowing will produce the notes of the next octave above the first

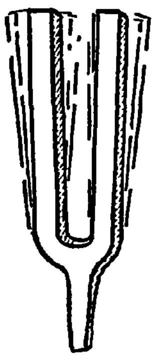


CHAPTER V

THE QUALITY OF SOUND

This is the most difficult chapter in this book, and if you leave it out it doesn't really matter In any case, don't try to remember it all—just try to understand it as you go along.

If the note middle C is played on the piano, then you hum it, and then someone plays the same note on a violin, anyone listening could quite easily distinguish the three notes from each other Yet they are all of the same pitch—all middle C, which has a frequency of 262 vibrations a second How is it then, that they sound different from one another, for they are very different? This sort of difference is known as difference in *quality* of the sound



We have so far been considering the note produced by a piano string or the human voice or a violin string as though it were one single pure note of a certain fixed frequency Actually very few sounds we hear in everyday life are as pure as that The note given by a good tuning-fork when it is struck gently is practically pure; it consists of one note of a certain frequency, and that note only But the sound of a plucked string is not a single pure note There are other notes mixed up with it—notes that we call *overtones* or *harmonics* You learnt something about the overtones of pipes in the last chapter—here is an experiment to do on the overtones of strings

Overtones in Strings

You need the instrument you made for the experiments in Chapter III—piano wire or violin string stretched tightly between two bridges mounted on a wooden base Pluck the wire near one end and listen very carefully to

the note You may or may not be able to detect the higher notes at the same time as the main note or fundamental note. But if you touch the wire in the very centre with the corner of a handkerchief while it is still vibrating you will stop the fundamental note and then be able to hear one of the overtones very clearly This is the note exactly an octave above the fundamental It is produced when the string vibrates in two separate halves instead of a whole

When you pluck a string it is almost impossible to make it vibrate only as a whole It usually divides itself up in several ways into fractions—into halves, thirds, quarters, fifths, and so on—and each fraction also vibrates as a separate piece and gives its own particular note whose frequency depends on the length of the fraction

Pluck the string again This time you will probably be able to hear the first overtone, the octave, quite clearly now you know what to listen for

Now measure the total length of the string and put a tiny dab of ink on a point a third of the way along it Sound the string again and then touch this point with the corner of a handkerchief This will cut out both the fundamental and the first overtone, and this time you will hear the second overtone very clearly If you call the fundamental " doh " and the overtone the " doh " an octave higher the second overtone will be the " soh " above that Or in musical notation—

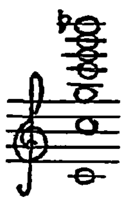
if the fundamental is tuned to middle C,  ,

the first overtone is the C an octave higher,  ,

and the second overtone is the G above that,  .

Now divide the string into quarters and find the third overtone The overtones above this are more difficult to

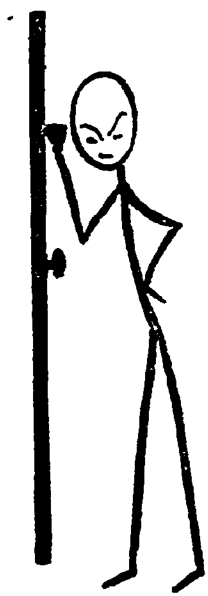
find, but if you have a good ear and you measure the distance along the wire exactly, you may be able to pick out the various overtones which sound as the string vibrates in fifths, in sixths, and so on



Here are the main notes sounding when a string whose fundamental is middle C is made to vibrate

The first six of these notes, including the fundamental, form the notes of a major chord when they are playing together; you can hear this if you pick them out on a piano Above that, however, many of the overtones form a discord with the fundamental In the case of a violin string the fundamental tone and the lower overtones are relatively much stronger than the higher overtones and the discordant notes are too weak to be heard The chord given by the lower overtones sounding at the same time as the fundamental makes the note of a violin string much richer than the pure note given out by a vibrating tuning-fork

Resonance in a Violin

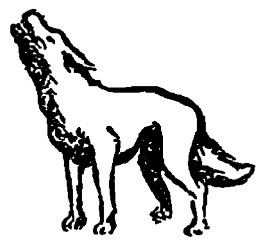


If the notes given by a violin depended only on the strings we should hear a number of pleasant sounds, but the peculiar richness and quality of violin tone would be missing altogether When a violin string is bowed not only the string itself vibrates, but also the bridge over which the string passes, and the front and back of the body of the violin, and every other part of it, including the air inside Now every solid object has its own natural frequency If you hit a piece of wood it vibrates and gives out a sound Take the case of a large piece of wood such as the panel of a door If you tap it with your knuckles you can hear the sound it makes as it vibrates with its own natural frequency. It is probably a rather low note Suppose you now sound a tuning-fork and press its foot on the panel of the door. The vibrating tuning-fork makes the panel vibrate in time with it, and instead of giving its own natural note the door panel gives this time the note of the tuning-fork If you have a large number of tuning-forks and you sound them each in turn in contact with the panel

you may find that in one case the note is unexpectedly loud That is because the vibrations forced on the panel by the vibrating fork are at the same rate as the natural vibrations of the panel on its own We might almost say that this is the rate at which the panel 'wants' to vibrate It is possible to force vibrations of any frequency on to a piece of wood But if the forced vibrations happen to coincide with the natural rate of vibration of the wood then the wood will vibrate much more readily, and the sound will, of course, be louder

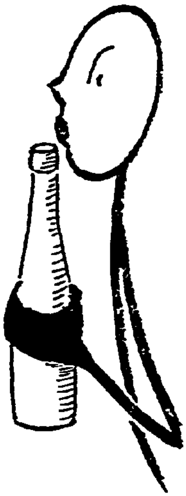
It is like that with a violin As each note sounds, all the solid parts of the violin vibrate at the same rate, and so they re-inforce each note But if the frequency of the note happens to coincide with the natural rate of vibration of any one part then that part tends to vibrate more easily and that particular note is re-inforced more As each note of the violin contains not only its fundamental but also a number of overtones it often happens that one of these overtones will be the same as the natural frequency of part of the body of the violin, and so that overtone will be re-inforced more than the others Every note on the violin has a different quality from every other note, as the proportions in which the overtones of the note are re-inforced by the body of the violin are bound to vary

There is one note on every violin that is very difficult to play without getting an unpleasant howling effect This is known as the "wolf" note The different parts of the violin all have their different natural frequencies, but the strongest is one of the notes given by the front part of the body If a string is vibrating with a fundamental note of the same frequency as this note the wood will vibrate so strongly that it upsets the vibration of the string The string then starts to vibrate in two halves, and its note leaps up to the octave above This is no longer the natural frequency of the wood, so the vibrations of the body die down until the string is able to resume its proper method of vibration. This sets the wood vibrating strongly again, and so the whole thing is repeated over and over again very quickly The result is a very unmusical howl Violinists



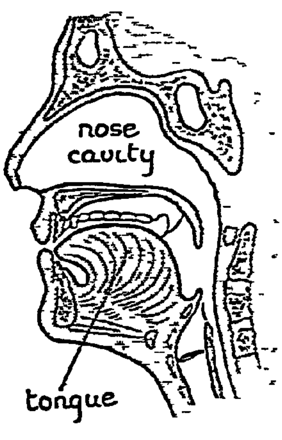
have to take great care when playing this particular note in order to avoid getting this howling effect, it can be avoided by very careful bowing of the string.

Resonance in a Piano



The picking up by one part of an instrument of a particular frequency corresponding to the natural frequency of that part is known as *resonance* You can demonstrate resonance very easily with an empty lemon-squash bottle With your mouth close to the mouth of the bottle sing a scale fairly loudly to " Ah ". One particular note will suddenly shoot out more loudly. This is the note corresponding to the natural frequency of the air inside the bottle. When this note is sounding the air in the bottle is set into strong vibration and adds its own contribution to the total effect. We say that the bottle is acting as a resonator.

The strings inside a piano also resonate when other strings are played whose upper overtones correspond to the natural frequencies of these strings Here is a simple experiment you can do Press down a key of the piano very gently so that no note sounds Keep the key depressed—this will remove the felt damper from the wires Now play the note an octave below the first one, but release the key of the second note, still keeping the first one depressed. You will at once hear the octave of the note you have just played The strings of the higher note are vibrating in resonance with the first overtone of the lower note, and the first overtone of a note is its octave

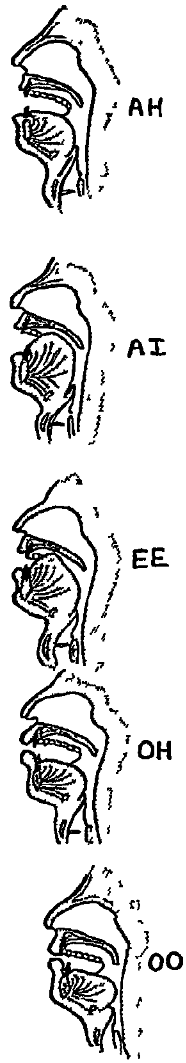


You can pick out the other overtones of a note in this way—try silently depressing the keys corresponding to the upper notes in the chord on page 32 while you play middle C Try the same thing for the harmonics of other notes and work out the positions of the upper overtones

The Quality of the Human Voice

In Chapter II we found that the pitch of the human voice is altered by stretching or relaxing the vocal cords in

the voicebox, or Adam's apple When the vocal cords are stretched they vibrate as we breathe through them If they are tightly stretched they vibrate quickly and the note produced is a high one If they are less tightly stretched they vibrate more slowly and the note produced is lower But the human voice, like the bowed violin string, never produces a perfectly pure simple note of just one frequency There are always many overtones and notes of other frequencies accompanying each sound we sing or say



As the breath passes out through the top of the windpipe it sets into vibration the air contained in the various cavities of the throat and nose and mouth Some of these cavities are shown in the diagram on page 34 The air in each cavity has its own natural frequency and when it vibrates it gives out its own natural note This is exactly similar to the way in which the air in a bottle vibrates and sounds a note as you blow across the top So in addition to the note given by the vocal cords we have the natural notes of all these air spaces And of course if the frequency of the vocal cord note, or one of its overtones, happens to be the same as the natural frequency of one of these air spaces, that particular note will be very much reinforced But this is not the whole story It is possible for the shape of the various cavities in the mouth to be altered by changing the position of the tongue and lips and teeth This alters the frequencies of these cavities and again modifies the sound produced

Try this now Sing the same note alternately to EE and OH Do you feel how you move your lips? Listen carefully to the notes Now try to do the same thing with your lips pressed firmly together You can make a sort of humming noise through your nose, but you will find that it is impossible to make the vowel sound clearly In fact, you cannot sound any vowel clearly with your lips completely closed Try it and see AH, AY, EE, AW, OH, OO, a, e, i, o, u, oo [1] Now why is this?

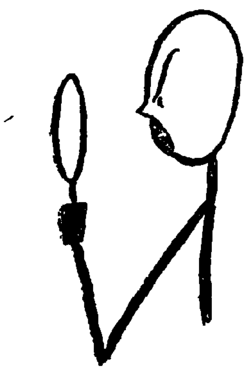
[1] The common vowel sounds occur in this order in these two sentences "Ma may we all go too?" and "That pen is not much good" You may meet them again if ever you learn shorthand.

Well, apart from the note you are singing all the separate vowel sounds have their own particular frequencies You may be able to detect this if you try just whispering the vowels Whisper EE and OO for example Can you hear that " EE " has a higher sound than " OO "? As a matter of fact each vowel sound is made up of two notes of different frequencies These notes are probably given by the vibrations of the air cavities of the mouth and throat, and altered to correspond to the different vowels

Consonants (b, c, d, f, g, etc) are sounded by forcing air between the lips (p, b, m), or between the tongue and the front of the hard palate (n, d, t), and so on It is probable that when the consonants are sounded the lips or tongue or teeth are themselves set into vibration and so they contribute their own particular frequencies to the complex sound pattern

By this time you will be thinking that the human voice, far from being one of the simplest musical instruments, is a very complicated one, and you will be right Many people have studied the human voice and have tried to reproduce its sounds artificially. Dr Erasmus Darwin,[1] for example, invented in 1770 a 'speaking' machine which, according to a friend of Darwin, " pronounced the *p*, *b*, *m*, and the vowel *a*, with so great nicety as to deceive all who heard it unseen, when it pronounced the words *mama*, *papa*, *map*, and *pam*, and it had a most plaintive tone when the lips were gradually closed ".

There have been many attempts at making speaking machines since then, but none of them has been wholly successful in reproducing the great range and quality of a real human voice



MORE THINGS TO DO

1 Stand in front of a looking-glass and notice the positions of your mouth as you say the different vowel sounds Some of them, like the AY of " say " are double sounds, or diphthongs Say them slowly and notice how your mouth alters its position

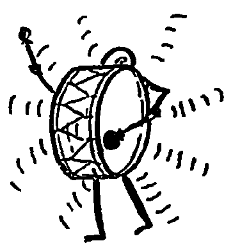
[1] Grandfather of the famous Charles Darwin who wrote about Evolution (see *Life and Growth*)

2 Make a point of listening carefully to people's speech especially over the radio You will know already that ways of pronouncing words vary in different parts of the country Many people think it would be very dull if we all spoke exactly alike On the other hand there are ugly sounds as well as pleasant ones How many ways do you know of pronouncing the two vowels in "I say"? Try these two words as you imagine a Cockney would say them, an Irishman, a very refined lady, a Yorkshireman, and so on How do *you* say them? Is there really a right and a wrong way?

3 Some people decorate the top of their piano with ornaments, photograph frames, and so on Quite often when the piano is played there will be an ugly jarring noise from the top when certain notes are sounded, but the jarring noise stops when one of the ornaments is moved Can you explain what causes this noise?

CHAPTER VI

HOW SOUND TRAVELS



Have you ever stood in a street and watched a long column of soldiers march by with a drummer and a band at the head of them? The drummer beats a tattoo on his drum and the soldiers time their steps to its rhythm, and presently the band joins in with a marching tune with a well-marked "1, 2, left, right" beat I expect you've watched the drummer as he hits his drum, and by this time you know exactly how you hear the sound When the drum is hit it vibrates backwards and forwards very quickly The skin of the drum pushes on the air next to it and makes the air vibrate, in time with the drum The vibrations spread outwards through the air until the air round you is vibrating too This air knocks on your ear-drum, and makes that vibrate, again in time with the drum And so you hear the sound Of course all this takes a little time to happen, but if you are standing fairly close to the drummer you hear the noise almost as soon as you see him hit the drum

But now imagine that you are standing not in the street itself, but in a balcony overlooking the street It is a very long straight street, so you can see a long way down it, and it is a very long column of soldiers that is marching along it. This time the band is playing too, a loud military march, and behind the band are rank after rank of soldiers all marching briskly in time with the music At least that is what they *think* they are doing But as you look over the heads of the marching column you notice a very odd thing All the heads in the front rows of soldiers, immediately behind the band, are bobbing up and down exactly together as the soldiers' feet march in perfect time with the music—left, right, left, right—a little bob for every step But half way down the column the movement of bobbing heads gradually changes While the heads in the front rows are bobbing *up*, the heads further along the column are bobbing *down* The soldiers in that part of the column are obviously half a beat out of step with those in front

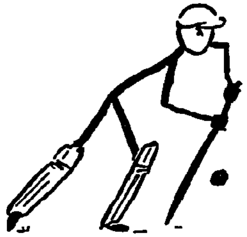
Why is that? While you are puzzling about it the band has marched by You can still hear them playing quite distinctly, but the sound is gradually getting more distant By this time the middle of the column is opposite the balcony where you are standing You watch the soldiers' feet carefully as they march past Left, right, left, right, one, two, one, two They seem to be in perfect time with the music after all, though their heads are still bobbing up while the heads of the front rows are bobbing down How is this? How is it that in every part of the column the soldiers are marching in perfect time with the music they hear, but they are *not* marching in perfect time with each other?

There is the problem for you. The answer is quite easy, and if you haven't already tumbled to it, read again the last sentence of the first paragraph of this chapter

Have you now got the explanation? The front row of soldiers heard the music practically the instant it was played So they marched in exact time with it But before the soldiers a hundred yards down the column could hear the music the sound had to travel that hundred yards along

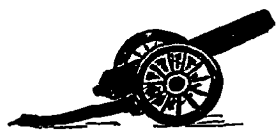
the road, and it took just about a quarter of a second to do it A quarter of a second does not sound very long, but it meant that the soldiers at this point heard the beats of the music a quarter of a second after the front rows heard it, and this was quite enough to make them make half a pace out of step

So sound takes time to travel Perhaps you have noticed that when you have been watching a cricket match You see the batsman swing his bat to meet the ball and you see the ball go flying, and a fraction of a second *after* that you hear the crack Or perhaps you are watching a couple of roadmenders some distance off swinging their sledgehammers You see each hammer hit the piece of iron that a third roadmender is holding in position, but the hammer is swinging up in the air again before you actually *hear* the blow. Or you may be at the seaside while target practice is going on out at sea A row of little white smoke puffs appears in the sky, first one, then another and so on—then some seconds later you hear a series of bangs Sound, you see, does not travel instantaneously—it takes time



THE SPEED OF SOUND

There are various ways of calculating just how fast sound can travel One of the first people to measure the speed of sound at all accurately was an English clergyman named William Derham He was the Rector of Upminster in Essex, which, two hundred and fifty years ago, was a small country village In the garden of Derham's house there was a telescope, and through that telescope he could see quite clearly the tower of North Ockenden church, which was exactly two miles away. Derham would get a friend at the church to fire a gun, and he would be able to see the flash quite clearly through his telescope He would then time the interval between seeing the flash and hearing the report and then work out how fast the sound had travelled He had a rather ingenious method of timing the seconds—it was a pendulum which took exactly a second to make its swing. With a little practice he found that he



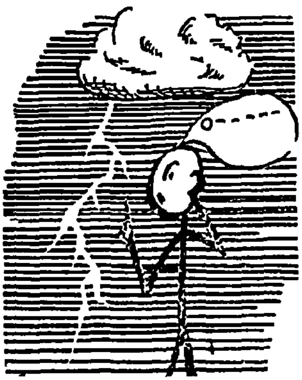
could measure times fairly accurately to a quarter of a second That is almost as accurately as anyone nowadays could measure time with a modern stop watch, though there are now, of course, many mechanical methods of measuring time far more exactly than that

Derham found that it took the sound exactly nine and a half seconds to travel the two miles from North Ockenden to Upminster. Two miles is 10,560 feet

10,560 feet in $9\frac{1}{2}$ seconds, how many feet in 1 second? Work it out

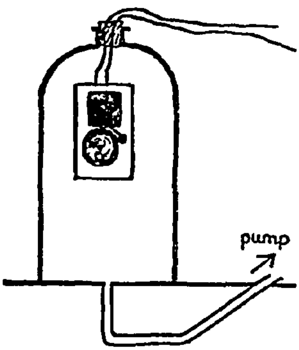
The figure we usually take nowadays is round about 1,100 feet per second, so Derham's result was a pretty good one

How Far Off?



Eleven hundred feet in one second is roughly a mile in 5 seconds or more exactly 750 miles an hour

If you practise counting to a watch with a seconds hand you can soon learn to time seconds fairly accurately· " *No*-little-second-*One*-little-second-*two*-little-seconds-*three* little-seconds" . . and so on Next time there is a thunderstorm near you, try to work out how far away it is When your thunderstorm begins wait for a flash of lightning and then count the seconds until you hear the peal (you should begin at 0 of course the instant you see the flash) Suppose you get up to ten seconds, then the storm must be two miles away Five seconds means that it is one mile away, one second, a fifth of a mile away, and so on It's very easy—try it next time there is a thunderstorm

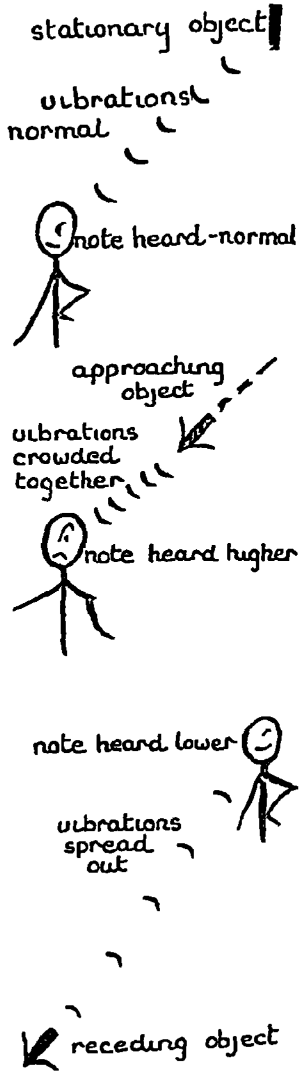


Sound in a Vacuum?

It is only possible for you to hear sound if the sound has something to travel through If you live in or near London perhaps you may be able to go to the Science Museum in South Kensington some time There are lots of interesting models that you can work by turning a handle or pressing a button, and a number of experiments set up for you to work

yourselves The most interesting part of the Museum from this point of view is the Children's Gallery, which is down some stairs on the left just as you enter the main part of the Museum One of the experiments consists of a big glass jar with an electric bell like a front door-bell hanging inside it If you press a button you can make the bell ring You can not only hear it, but see the clapper hitting against the bell as well Now the glass jar is also connected to an air-pump, and by moving a switch you can make the pump suck practically all the air out of the jar If you press the bell button and then switch on the pump the sound of the bell will get fainter and fainter, and finally you will not hear it at all, though you can see quite clearly that the clapper is still vibrating against the bell There is now, you see, no air inside the jar, and as sound cannot travel across empty space it is impossible for you to hear the bell If you release the pump handle you will let the air rush back into the jar, and as it rushes back the sound of the bell is heard once more for there is now air to carry it

Sound cannot travel through a vacuum



The Doppler Effect

Have you ever stood on the platform of a railway station while an express thundered through sounding its whistle? As the train approaches the sound of the whistle seems to get louder, but it keeps at the same pitch As the engine passes you there is a sudden drop in the pitch, and for a train travelling at about sixty miles an hour this drop in pitch is just about a tone

If you were inside the train instead of standing on the platform you would still hear the whistle, but this time the pitch would remain perfectly steady, a little lower than the pitch heard as the train approached and a little higher than the pitch heard as it receded

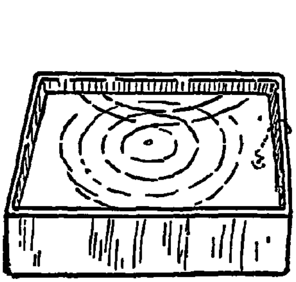
The apparent drop of pitch as a sounding object approaches and then passes an observer is known as the Doppler effect

The pitch of a note depends on the number of vibrations

reaching the ear every second The greater the number of vibrations the higher the pitch If a sounding object at a fixed distance from you is giving out say 440 vibrations a second you will hear the note A Now these vibrations travel through the air, and, of course, they take a certain time to travel Suppose now that the sounding object is moving towards you at a steady speed By the time the first lot of vibrations reach you the object is a bit nearer to you than when it sent them out, so the second lot will reach you a bit sooner than they would if the object were standing still This means that instead of arriving at the rate of 440 vibrations every second they crowd on each other's heels a bit faster as long as the object is approaching you Perhaps you receive, say, 466 each second This corresponds to the note of A♯, which is half a tone higher than the actual note the object is giving out As the object passes you, for a fraction of a second you will hear its true note as the vibrations will reach your ear at the same rate as they leave the object But as the object recedes from you it takes each successive vibration more and more time to travel from the object to your ear They lag behind each other, so instead of receiving 466 of these vibrations every second your ear may only receive, say 415. This corresponds to the note A♭

So although the true note given out by the moving object might be A *natural* (and this is the note you would hear if you moved with the object) you hear first of all A♯ and then A♭.

The exact amount by which the note drops in pitch depends on the speed of the moving object The faster it is travelling the greater the apparent drop in pitch Try listening for this drop in pitch when a fast car passes you on the road, or it is often very noticeable when a fire engine rushes by clanging its bell



Echoes

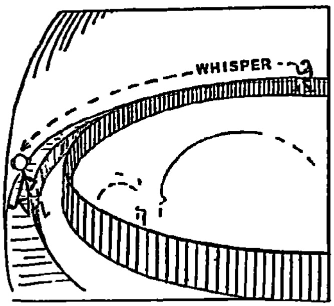
Drop a small stone in the middle of a bath of water and watch the ripples You will first of all see them spreading

out from the point the stone entered the water, then they will hit the side of the bath and be reflected back by it

If you stand in the mouth of a cave or a tunnel and shout you can hear the noise of your voice reflected back to you from the walls This reflection is known as an echo, and it is formed by the sound vibrations in the air hitting the wall and being reflected back in much the same way as ripples in water are reflected by the sides of the bath

In the open country you can often get a single distinct echo from a distant building or cliff or even from the row of trees at the edge of a forest Occasionally the note of the echo sounds an octave higher than the original sound This has been known to happen when a woman's voice was reflected by the edge of a pine-wood Perhaps the explanation was that the fundamental note of her voice with its low frequency was able to get through the wall of pine-needles, but the overtones with their higher frequencies were reflected

Inside buildings such as town halls you can often hear the sounds of a speaker's voice ringing round and round the room for some seconds after he has spoken This, of course, makes it very difficult to hear what he is saying The sound of his voice is reflected backwards and forwards by the ceiling, the floors and the walls It is not always very easy to design a large building so that there are few or no echoes, but hanging a wall with soft furnishings helps to deaden a sound When a hall is full of people there are fewer echoes than when it is empty This is because the clothes of the people absorb the sound that would otherwise be reflected from parts of the walls and the floors Many school halls are badly designed for sound, and sometimes you find that one part of a hall is much better than the rest



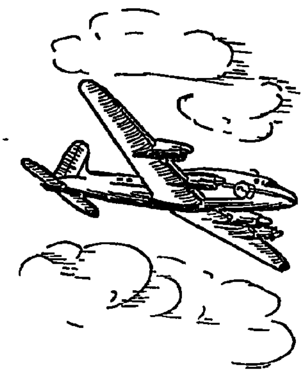
A very good example of the reflection of sounds by the walls of a building is inside the whispering gallery in St Paul's Cathedral in London This is a circular gallery running round inside the great dome If you stand with your mouth close to the wall and whisper, the sound can be heard by someone on the other side of the gallery

standing with his ear near the wall This is because the whisper is reflected from one part of the curved surface to another and so on all round the gallery

Another well-known echo in a London building is inside the Victoria and Albert Museum If you stamp on the floor just below the octagonal dome in this museum you can hear a number of echoes as the sound is reflected from different surfaces inside the building

Some blind people are very skilful in making use of echoes to tell how large a room is, or how far they are from an obstacle There was a famous blind judge who could estimate the length, breadth, and height of a room to within a foot simply by listening to the reverberations of his own voice in it We are all able to make use of this power to a certain extent when we move about in the dark, we automatically listen to the reverberation of our footsteps along a dark passage, for example, and can judge to some extent where the end of it is

Certain animals have this power developed to a remarkable extent It is well known that bats can fly about in a dark room across which wires have been stretched without bumping any of the wires People who have studied bats tell us this is because they are continuously giving out a series of high-pitched squeaks, too high for our ears to hear They listen for the reflection of these sounds from obstacles in their path, and when they hear the echoes they are able to swerve and avoid the obstacles



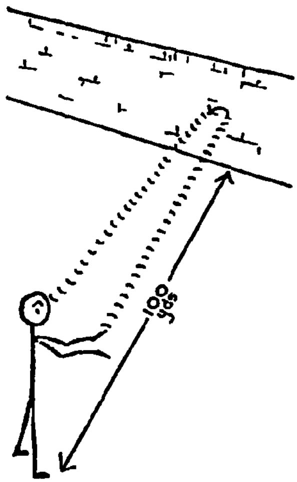
Things to Do

1 Next time an aeroplane passes overhead close your eyes and point in the direction you think the sound is coming from You will probably find when you open your eyes that you are pointing to a spot some distance behind the aeroplane Can you explain the reason for this?

2 An aeroplane has now been invented which can fly at a speed of between 800 and 1,000 miles per hour. If such an aeroplane were flying straight towards you explain why you could not hear it coming

3 Find a high wall facing an open space which gives a sharp

echo when you shout or clap your hands You can work out from the echo the speed at which sound travels



First pace out a distance of a hundred yards from the wall Clap your hands sharply together and listen for the echo

Clap *echo*

Between the clap and the echo the sound travels from you to the wall and back—that is a distance of $2 \times 100 = 200$ yards

Now try to clap your hands in exact time after each echo so that you get a regular rhythm like this

Clap *Echo* Clap *Echo* Clap *Echo* etc

Between each clap and the following echo the sound travels 200 yards We could show it like this

Clap *Echo* Clap *Echo* Clap *Echo* etc

200 yards 200 yards 200 yards

If you leave exactly equal intervals the sound could travel another 200 yards between each echo and the following clap

Clap *Echo* Clap *Echo* Clap *Echo* etc

200 yds 200 yds 200 yds 200 yds 200 yds

Get a friend with a seconds-hand watch to time you and count the *total* number of claps and echoes in a minute

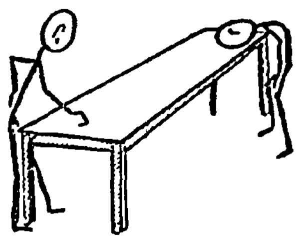
Clap *Echo* Clap *Echo* Clap *Echo* etc
0 1 2 3 4 5 etc

Multiply this number by 200 and you have the total number of yards that sound can travel in a minute

You could convert this to miles per hour or feet per second and see how your results agree with the numbers given in the chapter

CHAPTER VII

SOUND IN SOLIDS AND LIQUIDS

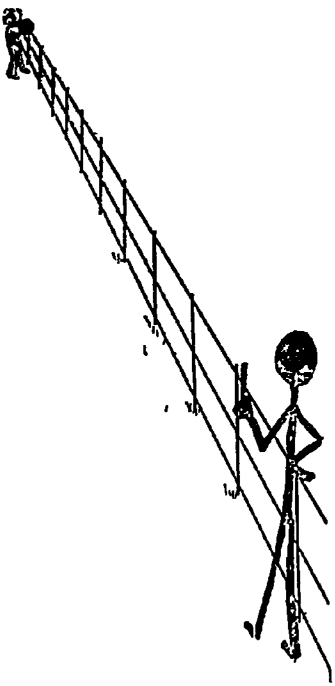


If you have a long table here is an experiment you can do now Hold your ear to one end of the table and get someone to tap or scratch the other end Do you hear the sound better through wood or through the air? If the

scratch is a very gentle one you should be able to hear it through the table quite plainly even though it may not be audible when you lift your head

Sound travels very well in wood, but better in some woods than others When a piano is being made Norway spruce is used for the soundboard as sound travels very quickly in this kind of wood It is important that the vibrations should spread quickly to all parts of the board so that the whole of it should vibrate together The sound travels more quickly along the grain than across the grain, so ribs are fixed across the grain to help the sound to travel The speed of sound in Norway spruce is about 15,000 feet per second, that is nearly fourteen times faster than it is in air

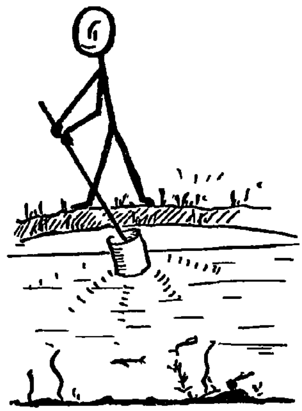
In old churches and other buildings you often find a little insect called the death-watch beetle Perhaps you have heard it if there is an old church near where you live It is called the death-watch because superstitious people used to think that the noise had something to do with human death But all the creature is doing is knocking with its head against the wood—probably sending messages to another beetle People who have kept death-watch beetles say that it is quite easy to make them answer the rapping of a pencil on the table



Sound travels very easily along many other solids besides wood Perhaps you have seen one of those Western films where the hero dismounts from his horse and puts his ear to the ground to listen for the sound of distant horsemen The noise of the horses' hooves travels far better through the earth than it does through the air You have probably noticed how easily it travels along an iron pipe in a house In some houses you can hear in the bathroom anything that is said in the kitchen below—the sound travels up through the water-pipes and the iron bath acts as a sort of sounding-board

The rate at which sound travels in iron is about fifteen times as fast as its rate in air If there is a park near your home with a long uninterrupted stretch of iron railing in it you can easily do an experiment to show the difference

in these speeds Put your ear to one end of the railing and get a friend some distance away to hit the railing with a piece of wood or a hammer You will hear the sound twice First it will come through the iron then it will come through the air Between the two sounds there is an appreciable gap, showing that sound travels faster in iron than it does in air



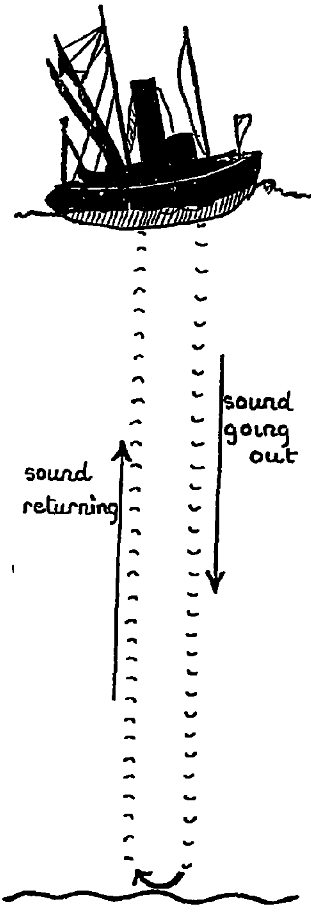
Sounds in Water

If you are a good swimmer and do not mind getting your head wet you can find out how easily sound travels through water, next time you go to the swimming-baths Float a hollow tin can on the water and get a friend to rattle a key or a stick inside it If you now swim under water you should be able to hear the sound quite clearly

Echo-Sounding

Sound travels about four times as fast in water as it does in air The speed of sound in water is made use of in an instrument for measuring the depth of the ocean in any particular place The old way of doing this is to drop a lead-line overboard and pay it out until the weight at the end touches the bottom The length of the line tells you how deep the water is But this method has many disadvantages One is that it takes a considerable time where the ocean is very deep, and the line may of course be swept to one side by currents or get tangled up with seaweed A much more accurate method is echo-sounding

If you stand some distance from a wall or cliff and then shout the sound travels through the air and then is reflected back from the wall as an echo The same sort of thing happens in water A sound started at the surface of the sea travels down until it hits the floor of the ocean, and then it is reflected upwards again as an echo At the bottom of many ships there is a special apparatus for echo-sounding A sound is sent out, and this travels through the water down to the sea-bed and up again The apparatus picks



up the sound on its return and records exactly how long it took on its double journey If you know the speed of sound in water it is quite easy to work out from this how deep the ocean is in that particular place

Echo-sounding is also used in deep-sea fishing, the echoes are reflected from a shoal of fish in much the same way as from the ocean bed.

Echo-Sounding in the Earth

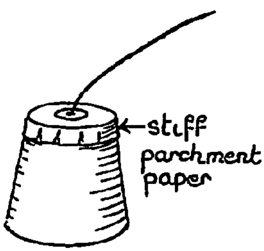
It is possible to discover the presence of certain minerals in the earth by echo-sounding Prospecting for oil is now done in this way The method is rather more complicated than echo-sounding in the ocean, but the principle is the same The sound of an explosion is sent down through the earth, and if it meets a layer of oil-bearing shale, part of the sound is reflected up again The depth of the oil can be calculated and also the extent of the oilfield This method was used in prospecting for oil in the British oil-field near Nottingham

Something to Make

Here is a string telephone which is very simple to make and fun to play with

You need a very long piece of string (the shiny even cord you buy in a ball is the best to use), some stiff parchment paper, and two cardboard ice-cream tubs—as large as possible, or you could use cocoa tins

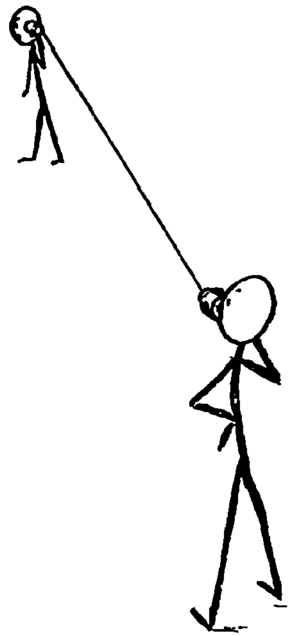
Cut the bottoms from the cardboard tubs and dampen two rounds of paper to stretch it and then glue them very firmly across the ends of the tubs to make two little drums When the glue is quite set and the paper perfectly dry make a small round hole in the middle of each drum and thread an end of the string through it, knotting it on the inside It is perhaps a good plan first to strengthen the hole by sticking a small ring of gummed tape on either side of it



Stretch your string very carefully across the school playground, making surè it does not touch anything If you hold one tub to your ear and a friend speaks into the other you will hear him quite plainly The vibrations from his voice set the drum vibrating and

the sound is carried along the string to the other drum which vibrates in time with it, and so you hear the sound

Perhaps you can invent a simple experiment to find out whether sound travels more quickly through string or through the air



CHAPTER VIII

HOW WE HEAR

The diagram on page 51 shows what the inside of your ear is like It is about twice the size of a real ear, but some of the parts for the sake of clearness have been drawn rather bigger than that

You remember that we hear sounds as a result of something setting the air vibrating and the air knocking on our ear-drums and making them vibrate too That, of course, is only the beginning of the story as far as hearing is concerned The real part of our hearing apparatus is right inside our heads

The ear really consists of three parts—the outer ear which we already know something about, the middle ear, and the inner ear

The Outer Ear

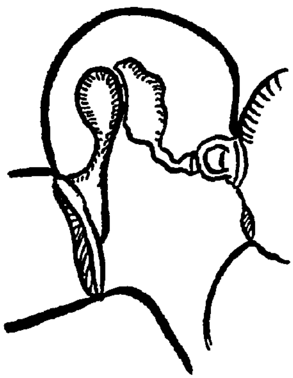
If you are standing in a quiet room with a clock in it you can probably hear the ticking from some feet away If you now cup your hand and hold it so that the edge of your hand touches the rim of your ear, the ticking becomes much louder You have made a hollow resonator which intensifies the loudness of the ticking In animals such as horses the large outer ear is movable and helps the animal to locate the direction of a sound, it also acts as a resonator and intensifies the sound Although most of us are not capable of moving our outer ears; the hollow part in the middle does to some extent act as a resonator for notes of certain frequencies

The outer ear has another use as well If sound travelling through the air hits a perfectly flat surface it is reflected straight back again, but if the surface is uneven the sound waves are scattered in all directions. This is what happens when sound waves reach the rolls and curves of our ears, and there is more chance of some of the scattered waves finding their way down the little tunnel which leads to the ear-drum than if the sides of our heads were perfectly flat

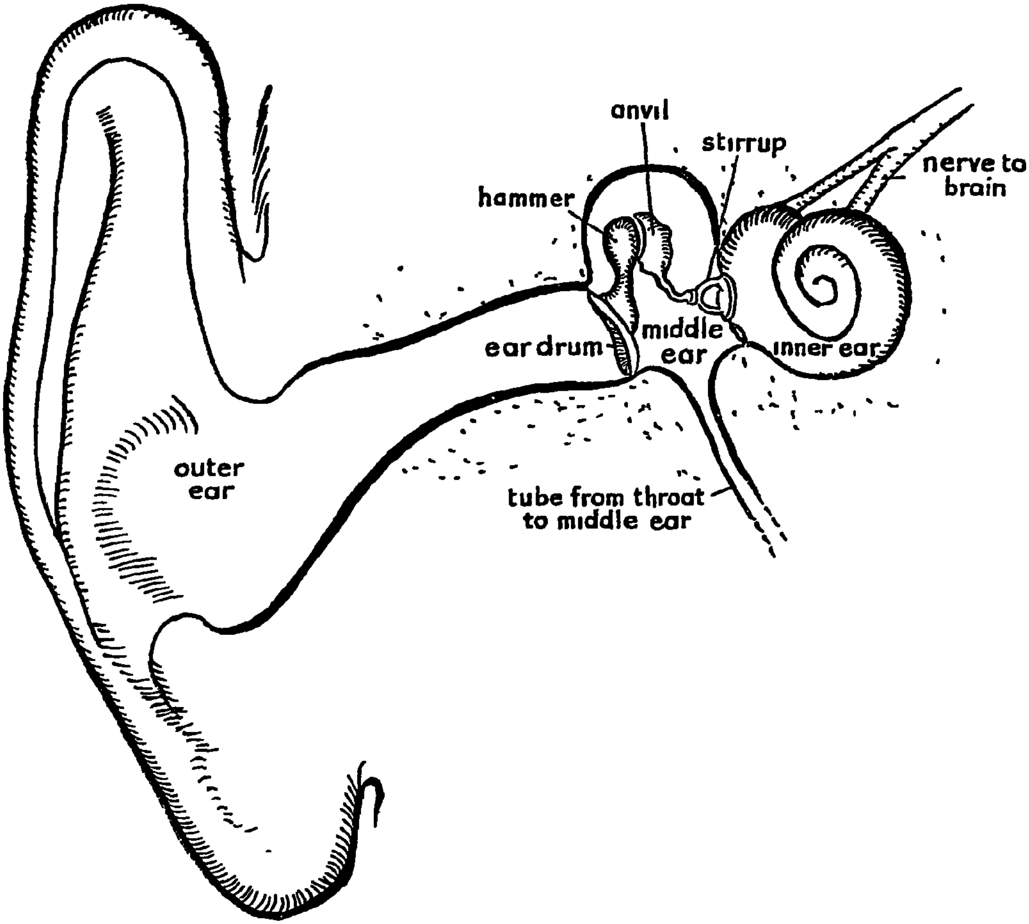
The ear-drum is a very thin membrane tightly stretched across the end of the outer tube of the ear It is only three-thousandths of an inch thick (If you have a very accurate ruler measure the thickness of this book, then divide by the number of sheets of paper to find the thickness of this page How many times thinner than this page is the membrane forming your ear-drum?)

As the drum is so thin it does not do to treat it roughly Never poke your fingers or anything else in your ears If you ever get too much wax in the outer tubes of your ears (and many people are troubled in this way) get a doctor or a nurse to syringe it out for you They know how to do this without damaging the ear-drum

The Middle Ear



The ear-drum cannot vibrate properly unless it is freely supplied with air both sides The middle ear is a hollow box about half an inch high, and it contains air. It is supplied with air by a passage called the Eustachian tube leading to the back of the throat For the ear-drum to vibrate properly the air on both sides has to be at the same pressure. The Eustachian tube is usually closed but it opens when you scream or swallow or yawn When a pilot in an aircraft dives from a great height the air pressure around him increases very rapidly This would cause his ear-drums to bulge inwards and would be very painful unless he did something to equalize the air pressure the other side of the ear-drum Many pilots nowadays have



THE HUMAN EAR, simplified and enlarged

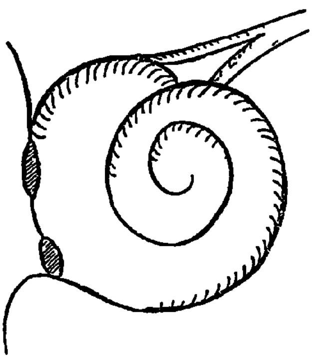
learnt the knack of keepmg their Eustachian tubes open when they dive, swallowing at frequent intervals or screaming also has the same effect

When you have a cold your Eustachian tubes often become blocked up with mucus, and this interferes with the vibrations of the ear-drum and also the smooth working of the three little bones which form a chain across the middle ear

These three little bones are called the hammer, the anvil, and the stirrup The hammer is connected to the ear-drum, and the stirrup presses against a little oval window the other side of the middle ear The vibrations of the ear-drum are carried across the middle ear by these three little bones and handed on to the most important part of the ear, the inner ear, where the vibrations are translated into messages for the brain

The Inner Ear

The inner ear also contains organs that affect our balance, but as these have nothing to do with the hearing apparatus we will not spend any time on them in this book



The part of the inner ear concerned with hearing is a tube known as the *cochlea* This is a word that means a shell, and the tube is called this because it is coiled round just like a snail shell The cochlea contains liquid, not air Air can be compressed, but liquid cannot, so there are two little windows between the middle ear and inner ear, the oval window already mentioned and another below it known as the round window These two windows are covered with thin but tough membranes. When the stirrup vibrates against the oval membrane and drives it inwards, the extra pressure of liquid in the inner ear forces the round membrane to bulge outwards, so the round window acts as a kind of safety valve.

If the cochlea were uncoiled the total length of the tube would be rather more than an inch Running along this tube is a membrane which has thousands of fibres stretched

across it These fibres are longer at one end of the membrane than at the other They are rather like the strings of a microscopic piano—comparatively long and slack one end, and short and tight the other Scientists think that these fibres must act as resonators, each one picking up notes of a certain frequency to which it is tuned There are also a great number of other fibres and tiny hairs inside the cochlea, but as the whole apparatus is so small and so complicated it is hardly surprising that scientists do not yet fully understand exactly how this part of the ear works

Attached to the hair cells inside the cochlea are a great number of nerve-endings, and these combine together to form the big auditory nerve that carries messages, this time not as sound vibrations but as electrical impulses, from the *cochlea to the brain*

Differences of Loudness

Our ears are surprisingly sensitive in a number of different ways We can distinguish between notes of many different frequencies And we can often pick out notes of certain frequencies from a mixture of several others and give our attention to, say, one particular musical instrument in a quartet, or one particular voice in a roomful of people talking

Let us think about loudness first of all It is really amazing that our ears, which are sensitive to the ticking of a watch several feet away in an otherwise quiet room, are not shattered by the scream of an engine whistle or the roar of a nearby pneumatic drill

If a noise gets louder and louder we first of all begin to find it unpleasant, then uncomfortable and finally it causes us acute pain and may even injure our ears

It is possible to measure the loudness of the various sounds we hear, and here is a table of some ordinary sounds arranged in order of average loudness, the unit used in measuring the loudness of sounds is called the *phon* We are unable to hear sounds of very low intensity,

though these can be detected by scientific instruments The point at which sound becomes audible we call the "threshold of hearing" and the scale begins at this point with a loudness of 0 phons

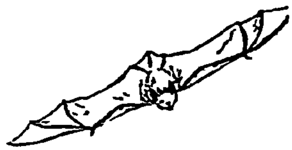
Threshold of hearing	0 phons
Gentle rustle of leaves	10 phons
Quiet whisper 4 feet away	20 phons
Sounds in a quiet London garden	30 phons
Sounds in a quiet suburban street	40 phons
Conversation 12 feet away	50 phons
Ordinary conversation	60 phons
Sounds in a busy main street	70 phons
Lion roaring 20 feet away	80 phons
Tram passing 4 feet away	90 phons
Pneumatic drill 10 feet away	100 phons
Noise inside boiler factory	110 phons
Aeroplane engine 10 feet away	120 phons

These numbers are of course only approximate, but you could think of a few more ordinary sounds for yourself and decide where on the scale of loudness you think they should come

At loudnesses greater than about 130 phons it is difficult to distinguish between the sensation of loudness and the sensation of pain While loud sounds hurt our ears, extremely loud sounds may deafen us, as the ear-drum is made to vibrate with such intensity that it is broken. You have probably heard of people being deafened in this way by the noise of an explosion

Differences of Pitch

Some people have very much more sensitive ears than others when it comes to distinguishing between notes of different pitches The lowest noise most of us can hear as a musical tone has a frequency of about 20, and the highest about 20,000 vibrations per second Young people can often hear higher notes than that—up to a frequency of about 25,000 This is about the pitch of a bat's squeak



If you live in a place where there are bats find out which of your acquaintances can hear their squeak and which cannot You will find that grown-up people have ears less sensitive to notes of very high frequency than children In fact, many grown-up people cannot hear notes of a higher frequency than 10,000

Between the limits of 20 and 20,000 you could, of course, have any number of different notes with frequencies differing from each other by a few vibrations only per second or even by a fraction of a vibration per second But even if you were to construct an instrument to play all these different notes your ears would not be sensitive enough to distinguish between them

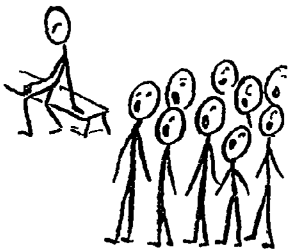
When we are tuning a piano, for example, we arrange the notes of our musical scale in semitones, and each semitone has a frequency about 1 06 times higher than the note below The A above middle C, for example, has a frequency of 440 A♯ has a frequency of $440 \times 1\ 06 = 466$[1] The note above that, B, has a frequency of $466 \times 1\ 06 = 494$ C has a frequency of $494 \times 1\ 06 = 523$ And so on

Now most people can distinguish between semitones quite easily But then there ought to be a considerable difference between a note of frequency 494 and one of 523 vibrations a second A musician with very sensitive ears can distinguish two notes much closer together than that

In fact, under very special conditions of testing with perfectly pure tones it has been found that some people can tell the difference between two notes which differ from each other by as little as $\frac{1}{30}$ of a semitone For two notes near the C whose frequency is 523 this means a frequency difference of approximately one vibration per second

In everyday life the smallest difference in pitch which even a trained ear can detect is generally a good deal greater than this, though most of us can hear that a note is out of tune when it is about one-sixth of a semitone sharp or flat

[1] These frequencies are given here to the nearest whole number



However, there are people who find it difficult to distinguish notes even a semitone apart These people are described as tone-deaf A scientist who made many important experiments on sound suggested that all schoolchildren should be carefully tested to find the smallest differences between frequencies that they could detect, those who could not tell a difference of a semitone should have nothing whatever to do with music—both for their own sakes and that of other people Do you agree with this?

In Indian music and the music of other Eastern countries our Western scale is not used Some Eastern music uses smaller intervals than our semitones—about ¼ tone between two successive notes This sounds very strange to our ears accustomed to the Western scale, but our music sounds equally strange to people used to Eastern music only There is a story of a Chinese lady being taken to hear an orchestral concert for the first time When she was asked how she liked it she said that the part she enjoyed best was the short piece right at the beginning She meant the orchestra tuning up!

Absolute Pitch

Some people are able to recognize and name the pitch of any musical note whenever it is sounded Such people are said to possess the gift of absolute pitch A person with absolute pitch can point correctly to any note on the piano after it has been played while he was standing with his back to the instrument He is able to recognize correctly the note of a motor-horn or engine-whistle as A or F♯ or whatever it may be He can tell at once the key in which an orchestra is playing or an errand boy whistling Occasionally people possess this gift without knowing it You might ask your teacher to test your class during a singing lesson One week perhaps he or she would play to you several times all the notes from say the G below middle C to the G two octaves above, telling you the name of each note as it is played At the beginning of the next week's lesson you might try writing down the names of

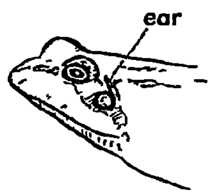
any of these notes as your teacher plays them at random You might also try humming a note and then seeing if you can pick it out correctly first time on the piano Anyone who possesses absolute pitch should certainly learn to sing or to play some musical instrument, it is a very remarkable musical gift, so if you are one of the few lucky ones to possess it, don't waste it!

Hearing in Other Animals

We have already mentioned that some animals such as dogs and bats are capable of hearing sounds of a higher frequency than those that we can hear It has been found by experiment that dogs are also far more sensitive to small differences in frequency than we are, and also to small changes in rhythm Hearing in man, then, is not as acute as it is in some other mammals [1] On the other hand, man is the only mammal who is able to understand the thousands of shades of meaning in human speech It may be that so much of the human brain is concerned with this aspect of hearing that less is available to deal with the slight differences in pitch and rhythm so easily recognized by a dog

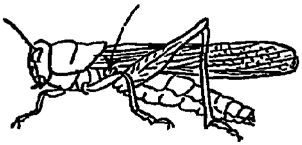
The ears of mammals are all constructed on more or less the same pattern as human ears, though there are, of course, differences in the outer ear The ears of birds,[1] and of reptiles[1] and amphibians[1] are also very much like ours, though simpler, these animals have no external ears for example, and the cochlea is less complicated in design

In frogs the ear-drum is flush with the skin and can easily be seen as a circular patch behind the eye Frogs are able to hear sounds and respond to some sounds such as the croaking of other frogs Snakes on the other hand are deaf as far as air-borne sounds are concerned, though they are able to hear sounds conveyed along the ground, they have no ear-drum, and the cochlea is connected by a short rod to a bone of the skull Sounds transmitted by the



[1] For definitions of these terms see *Life and Growth*

ground are conveyed through the bones of the snake to this little rod and thence to the cochlea Perhaps you have seen a film of a cobra swaying to the music of a snake-charmer's pipe It has been found that the cobra is completely unaffected when the musician is hidden behind a screen The cobra in fact is quite deaf to the music, and when it sways it is probably just following the motions of the snake-charmer's body



Soft-bodied animals such as worms and jellyfish and slugs have no organs of hearing, but there is one other group of animals where ears are occasionally present, this is the group of insects [1] Some insects, such as some species of grasshopper and cricket, have ear-drums not in the place we should expect them, but on their legs! In others the ear-drums are on the body, just below the wings, or on the abdomen The caterpillars of some insects have been found to respond to sounds, though they do not possess ear-drums, it is thought that the hairs on their bodies may be somehow sensitive to sound-vibrations

Things to Do

1 Blindfold someone and then try the experiment of clicking two pencils together in various parts of the room while he points to the direction he thinks the sound is coming from Is he able to judge whether the sound is coming from his right or his left? Can he tell correctly each time whether it is coming from the front or the back?

2 If you are interested in singing you can probably sing a chromatic scale in semitones There will be thirteen notes from doh to upper doh (practise it once or twice with a piano to get the idea) Now what about quarter-tones? Can you sing a scale with twenty-five separate notes in it instead of thirteen? Violinists can easily play in quarter-tones if they want to and there have been pianos made which would play in quarter-tones

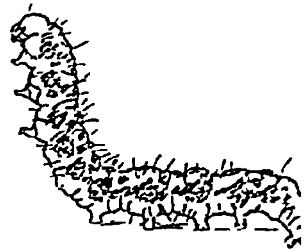
3 If you keep caterpillars at school try sounding a whistle or a tuning-fork near them to see if they respond to sound Some kinds said to do this include caterpillars of the Large White Butterfly, the Large Tortoiseshell, the Small Tortoiseshell, the Peacock, and

[1] For the differences between animals with backbones, such as mammals, birds, etc , and those without, such as insects, see *Life and Growth*.

several kinds of Tiger Moth The caterpillars respond to the sound by raising the front parts of their bodies suddenly in the air Try with notes of different pitch and loudness

4 Find out from a biology book how crickets and grasshoppers produce their chirping noises

5 How many wild birds can you recognize from their song? If your school has a gramophone you may be able to borrow some Ludwig Koch records and learn some of the more common bird calls



CHAPTER IX

RECORDING SOUND

One day in the year 1877, the American inventor Thomas Alva Edison was at work in his laboratory at Menlo Park Around him were his assistants all busily working on one or other of Edison's inventions, and there were probably the usual workshop noises of hammering and sawing and so on These would not have bothered Edison, for he was very deaf, but even if he hadn't been deaf he had a remarkable gift for being able to concentrate on the thing he was working at When he was on a job he practically lived in his laboratory, eating there and snatching a few hours' sleep occasionally on a hard wooden bench, but never more than a few hours at a time, for Edison believed that sleep made people sluggish and lazy, he needed very little himself, and thought that most other people slept far too much

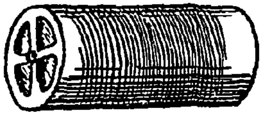
On this occasion he was making a drawing He put his pencil down and held the drawing out looking at it carefully "Yes", he thought, "that ought to work"

He called across the laboratory to his assistant Kruesi "Hey, Kruesi! Come here a minute I want you"

"Coming boss! Yes, Mr Edison, what is it?"

"Take a look at this drawing, Kruesi"

Kruesi looked carefully at the drawing It was a model



of some kind Edison explained the different parts to him

"This is a roller—a brass roller And this is a handle to turn the roller round Have you got the idea?"

"Yes, Mr. Edison, but what's it *for*?"

"And take a look at the roller I want you to cut a groove in it Like the thread of a screw—round and round the roller with the turns about a tenth of an inch apart"

"Yes, Mr Edison, I understand you, but what is it *for*?"

"The size of the roller should be—oh, about five inches long I should think"

"Yes boss, but what——"

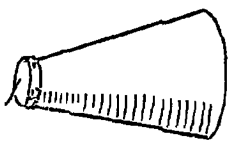
"And about four inches across And now take a look at this"

The other part of the drawing was more complicated Kruesi puzzled over it, still wondering what the apparatus was for

"What's it *for*?" said Edison "Oh, it's just a talking machine"

This gave Kruesi a bit of a shock A talking machine? He'd heard of machines that said "papa" and "mama" when you worked a bellows, but he didn't suppose that Edison meant anything like that He was quite right

"Now this curved tube," continued Edison, "this has to be made rather carefully"



"It seems to have a sort of horn at one end"

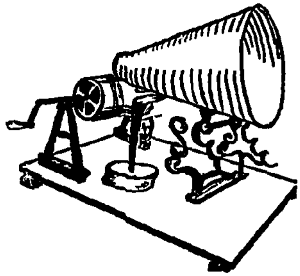
"Quite right, Kruesi That'll be the mouthpiece"

"Um And what's to be at the other end?"

"I want you to fix across that end a very thin sheet of metal—it must be very flexible It's got to act as a drum Do you think you understand?"

"I guess so, boss A thin metal drum O K"

"And on to the metal drum I want you to fasten a steel needle—not too sharp The whole thing has got to be fixed so that when you turn the handle the roller not only turns round but moves along, with the needle travelling along the groove Got it?"



Kruesi couldn't see at all how this apparatus was supposed to work, but he was used to Edison's ways, so he went off and made the model exactly according to the drawing

When it was finished Edison examined it very carefully and then he called all his assistants together "You are now," he said, "going to see and hear a most remarkable invention—the talking machine"

Edison's assistants were, I expect, too polite to reply to this, but no one could quite see how such a machine could possibly talk Edison gave a shout into the horn He asked one of his assistants to put his finger on the piece of thin metal stretched across the end "There!" he said, "Feel how that metal drum vibrates with my voice," and he shouted again They could understand that all right

"Now comes the tricky part Hand me that sheet of tin-foil, will you?"

The sheet of tin-foil was just big enough to wrap round the roller once with a very slight overlap Edison stuck the overlap down very carefully The brass roller with the groove cut in it was now covered with a very thin metal jacket

"Now we're ready to begin," said Edison "I'll say something to the machine, and the machine will say it back to me What shall I tell it?"

"*A nursery rhyme*," *someone suggested*

"O K" said Edison "Here goes"

He began to turn the handle It squeaked a little, but the roller with its tin-foil jacket turned smoothly The needle attached to the metal drum pressed lightly into the tin-foil as it moved along the groove "Mary had a little lamb," said Edison into the horn, "Its fleece was white as snow, and everywhere that Mary went, the lamb was sure to go"

There was a short silence in the laboratory Everyone wondered what was going to happen now

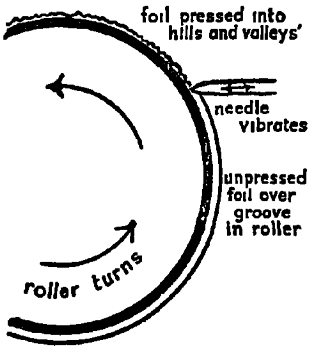
Edison carefully lifted the needle away from the drum and wound the drum back to where it started from He carefully placed the needle back in the groove

"Now!" he said

He began to turn the handle It squeaked a little, but the roller with its tin-foil jacket turned smoothly. The needle attached to the metal drum pressed lightly into the tin-foil as it moved along the groove "Mary had a little lamb," said a tiny metallic voice from the horn, "Its fleece was white as snow, and everywhere that Mary went, the lamb was sure to go"

"Good heavens", said Kruesi, "It really works!"

Yes, it really worked Edison had invented a machine that could talk Not just "papa" and "mama" and "map" and "pam" like the machine invented by Dr Darwin, but real words and sensible words, if you can call "Mary had a little lamb" sense But how did it work, this machine of Edison's?



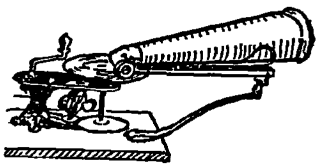
Well, when Edison spoke into the horn the metal drum across the end of the horn moved in and out vibrating in time with the vibrations of his voice The needle attached to the metal drum also vibrated of course, and as it moved over the tin-foil it indented a groove made up of a lot of little hills and valleys corresponding with the vibrations The tin-foil was soft enough to be indented fairly easily, but firm enough to keep the hills and valleys until the needle was moved over the groove for the second time.

This time the needle was made to vibrate not by a human voice but by the hills and valleys in the groove It forced the drum in and out, in and out, in exact time with the original vibrations of Edison's voice As the drum vibrated it made the air vibrate, and as the vibrations reached the ears of Edison and his assistants they heard the first sentence ever spoken by a machine. "Mary had a little lamb . ."

From Phonograph to Gramophone

That was the beginning of the gramophone. It was not called a gramophone then, but a phonograph. And for some years after Edison's invention phonographs were very popular. The records were not flat discs like the

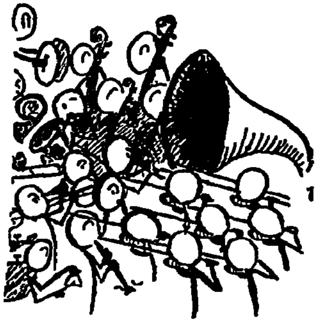
gramophone records you know to-day, they were round cylinders something like quarter-pound cocoa-tins in size and shape Edison improved his original phonograph very much, of course, before it was put on the market, and the records that were made to play on it were made of wax Unfortunately, wax does not last very well, and although you occasionally see an old phonograph in a junk shop, phonograph cylinders in really good condition are nowadays quite rare It is thanks to Edison and his invention that we still have records of some famous voices from the past, Lord Tennyson, for example, and the famous politician Mr Gladstone



In the year 1887 a new kind of talking machine was produced It was invented, also in America, by the German-born scientist Emile Berliner This time the record was made on a disc, and the vibrations in the groove were from side to side instead of up and down But the principle was much the same as in Edison's phonograph The new machine was called the gramophone, and it was the ancestor of gramophones of to-day

As time went on more and more improvements were made in the gramophone and in methods of recording The early models were turned by hand, later ones by clockwork Modern gramophones are often electric

How a Gramophone Record is Made To-day



At one time all recordings were made by the power coming directly from the source of sound The instruments of an orchestra, for example, made the air vibrate, the air made the drum attached to the cutter vibrate, so the record was cut Now this meant that all the instruments of the orchestra had to be crowded as closely as possible to the horn of the cutter, otherwise the sound intensity would be too feeble to make it work This was not only very uncomfortable for the players, but also it meant that the balance of instruments could not be arranged very well If you listen to one of these old orchestral recordings you will probably hear one kind of instrument,

violins perhaps, too loudly, but many of the others will be so faint that you can hardly tell they are there

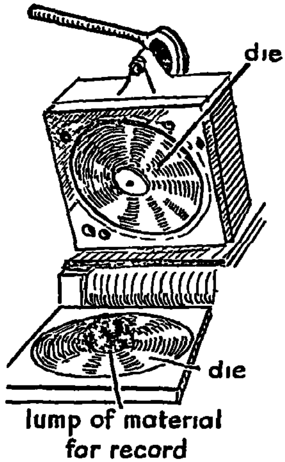
In 1924 a new system of recording was introduced—electrical recording This time the sounds of the orchestra were picked up by microphones, turned into electrical impulses, intensified by a valve, and the actual cutting gear on the recording machine was worked electrically This gave much more satisfactory quality to the record This is the method used to-day

The disc on which a recording is made is, to begin with, a plain disc of smooth soft wax This is placed in position on a turntable and the cutting needle is lowered on to it As the disc goes round, the cutter gradually moves inwards from the outside towards the centre so that it cuts a spiral groove on the disc The vibrations transmitted to the cutter make it vibrate from side to side in time with the sound vibrations from the orchestra or whatever it is that is being recorded So the groove, instead of having perfectly smooth sides, is a wavy groove Its turns are usually one seventy-eighth of an inch apart

This first disc is far too soft to be played, and so copies of it must be made from harder material The surface of the wax is first brushed over with graphite or some other substance which is a conductor of electricity It is then immersed in a solution of copper sulphate, and an electric current is passed through the solution from a lump of copper to the surface of the disc This process deposits a thin skin of copper on the disc, and when this is thick enough it is peeled off A spiral ridge takes the place of the spiral groove on the original disc, but the ridge has the same wave-pattern that the groove had (If you press your thumb on a piece of soft candle grease you can see how the grooves are " printed " as ridges and vice versa) The copper die could, of course, be used directly to stamp the records, but in case it is damaged several identical copies of the die are made, and one of these is used as a stamp

This copper die is now fastened to a firm backing for the press Another copper die carrying a different

recording is fastened to the other side of the press All is now ready to stamp the record The stuff from which the record is to be made is usually a kind of dough made from a mixture of shellac, resin, carbon, and other materials A lump of this dough is placed between the halves of the press The halves are then forced together, squeezing the dough out into a flat disc The pattern of the spiral ridge on the copper disc is printed on the disc as a groove, corresponding in every way to the groove on the original wax disc When the record is sufficiently cool it is removed, trimmed and polished and is then ready to be played

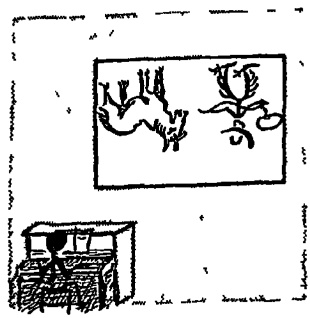


One of the great disadvantages of a gramophone disc of this kind is that it is not unbreakable There is, however, a new type of long-playing record which is described as 'unbreakable', and there appears to be no good reason why all gramophone records should not be made of similar material

Recording on Film

The method just described is not the only way in which sound can be recorded and stored and reproduced when wanted There are several other methods including tape recording, wire recording (both of these work magnetically), and three main methods of recording on a long strip of film Film recording is specially important, as it is used in the motion-picture industry

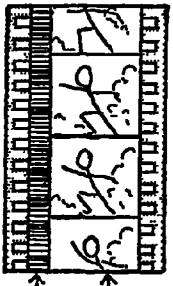
At one time all films were silent If you went to the cinema in the very early days the only sound you heard was the accompaniment from the pianist (cavalry charges for cowboys, soft bits for the love scenes), the whirring of the projector, and the various cheers and cat-calls from the audience Going to the pictures was far more of an adventure in those days—you never knew what was going to happen; sometimes the pictures even came on upside down Nowadays everything is very efficient The actors not only move about the screen, they talk as well



If you look at a piece of sound film you will see the sound

track running along one side of it This is a narrow band, and it may either have stripes across it of various shades of grey and black, or be solid black with a wavy edge We will describe how the first kind is made, which is known as the "variable density" method, the other kind is very similar

The sound vibrations are first picked up by a microphone and are turned into electrical impulses The electric current—varying according to the vibrations—passes through a special electric lamp, and the light from this varies in intensity according to the strength of the current This light passes through a slit and is recorded on the moving film in the same way as light in an ordinary photograph The film is developed and fixed The strips of varying densities on the sound track correspond exactly to the original sound vibrations.



In order to reproduce the sound from the film, light is passed through the sound track on to what is known as a photoelectric cell This is a kind of lamp through which a current is passing The strength of the current varies according to the intensity of light falling on it—in other words, according to the density of the strips on the sound track The current is amplified and works a loudspeaker The sound vibrations coming out of the loudspeaker correspond to the strips on the sound track which correspond to the original sounds

The chain of events is

sound vibrations → electrical vibrations → varying light
↓
strips on the sound track
↓
sound vibrations ← electrical vibrations ← varying light

Things to Do

1 Examine the grooves on a gramophone record through a powerful magnifying-glass You should be able to see that the grooves have wavy sides

2 Many second-hand shops have stacks of old records which they sell for a few pence If you can find one made before 1924 compare the quality of recording with that in a modern electrical recording

3 Most gramophone records are made so that the vibrations come out at the right rate when the turntable regulator is set at seventy-eight revolutions per minute Play part of a record of recorded music first at the correct speed then the same piece at a speed of 82 6 revolutions per minute What happens? Can you explain this?

(If you have good ears and a taste for arithmetic you may be interested to find that 82 6 is practically 78 × 1 06 Where have you met 1 06 before?)

4 Find out about the new 'long-playing' gramophone records, and how they are different from those described in this chapter

CHAPTER X

HOW SOUND IS TRANSMITTED

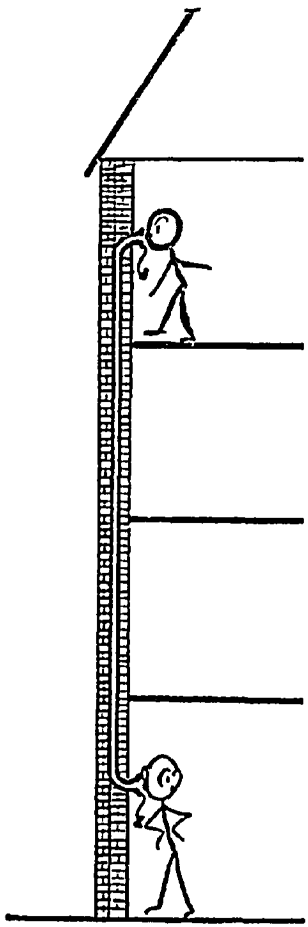
The word 'transmit' means to send something from one place to another Sound can be sent from place to place in a number of ways First of all it can just travel through the air as sound vibrations, or it can be turned into electrical vibrations and sent along wires for miles, or scores of miles, or hundreds of miles, and then be turned back into sound vibrations at the other end Or it can be turned into another sort of electrical vibration and be flashed across space as wireless waves, and then again be turned back to sound at the other end

Direct Transmission of Sound

We have already learnt quite a lot about how sound travels in Chapter VI The air, you remember, vibrates in time with the sounding object, these vibrations spread

outwards from the source of sound, then, if you are somewhere near, the vibrating air knocks against your ear-drum making that vibrate too, and so you hear the sound

But of course, the further you are from the sounding object, the feebler will be the sound you hear. The original sound waves are not only travelling in your direction, they are spreading out through the air in all directions If the sound could be made to travel in one direction only you would hear it more clearly This is more or less what happens when somebody speaks through a megaphone the sides of a megaphone prevent the sound spreading outwards and concentrate the waves in one direction only

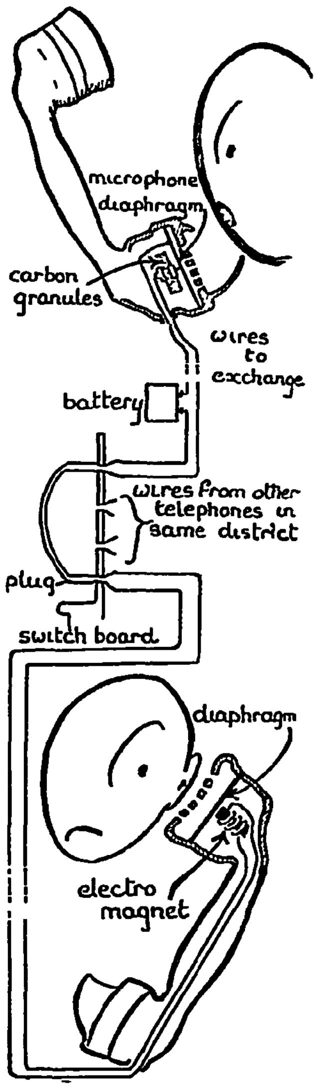


If you put the megaphone to your ear you can hear a distant sound rather better with it than without it This is because the mouth of the megaphone has a much larger opening than your ear, and so picks up more of the sound waves and reflects them inwards to your ear. This is the principle of the ear-trumpet that slightly deaf people sometimes use as an aid to hearing

Some restaurants and old houses are fitted with " speaking-tubes " leading from one room to another Doctor Darwin—you remember him in connection with the ' speaking machine '—was one of the first people to fit his country house with a speaking-tube which ran from his study to the kitchen Darwin was always experimenting with queer apparatus In those days country people were apt to think things they did not understand were witchcraft One day, or so the story goes, a countryman had called at Dr Darwin's house with a letter, and was sitting by himself in the kitchen waiting for a reply Suddenly a deep hollow voice, almost in his ear, announced, " I want some coals " The poor man nearly jumped out of his skin, and even when he had recovered from his fright he could never be persuaded to go near the house again, for he was sure, so it is said, that the voice belonged to the devil himself demanding fuel for the fires of hell

For a speaking-tube to be efficient the inside of it ought to be quite smooth, otherwise the friction of the air as it vibrates against the tube wastes some of the energy

of the sound All the bends in the tube must be curved, and there should be as few bends as possible If the tube were to turn sharply at right angles some of the sound would be reflected back along the way it came If the tube is a good one a lot of the sound from a voice speaking into one end of the tube travels along the air inside it instead of spreading out in all directions, and can be heard quite distinctly by someone with his ear to the other end, even if he is several floors away



The Telephone

Speaking-tubes are no good over very long distances, but it is quite possible for someone in London to hold a conversation with someone in Edinburgh by telephone

The telephone is another of the inventions that Edison had a hand in, though he was only one of a number of people who helped in its development The man usually remembered as the inventor of the telephone is Alexander Graham Bell, though many other people were working on similar ideas at the same time, and many more people helped to perfect Bell's instrument

It is sometimes possible to buy an old Services telephone for a few shillings, and it may be that your school can get one of these If so, you can take it to pieces to see the different parts and then, if you haven't lost some of the bits, put it together again, if you have a battery you may be able to fix it up so that you can talk from one room to another

An ordinary telephone consists of a transmitter and a receiver, both connected by wires to the telephone exchange When you lift a telephone off its stand you automatically make a connection which allows an electric current to flow along the wires from the mouthpiece to the exchange Inside the mouthpiece, or transmitter, there is a diaphragm which vibrates with your voice as you speak As it vibrates the diaphragm presses on some grains of carbon packed rather loosely in a little box The electric current flows through these carbon grains When they are

pressed more closely together the grains conduct the electricity better than when they are released As the vibrating diaphragm alternately presses and releases the grains, so the electric current gets alternately stronger and feebler These variations in the electric current correspond exactly to the variations in the sound vibrations We might almost say that the sound vibrations have been turned into electrical vibrations

The current, carrying the 'electrical vibrations', passes along the wires and so to the telephone exchange Here the operator connects the wires from your telephone with those of the person to whom you wish to speak (if it is a local call; if not, the call may have to go through several exchanges first) The electric current from your transmitter now flows along the wires to the receiver the other end The wire is wound round an electromagnet inside the receiver which almost but not quite touches the receiver diaphragm. As the current gets alternately stronger and weaker, so it makes the magnet pull on the diaphragm alternately more strongly and more weakly The diaphragm therefore vibrates in time with the electrical vibrations, and so produces sound vibrations corresponding exactly to the sound vibrations from your voice Anyone listening at the receiver end therefore hears you speaking

Hearing Aids for Deaf People

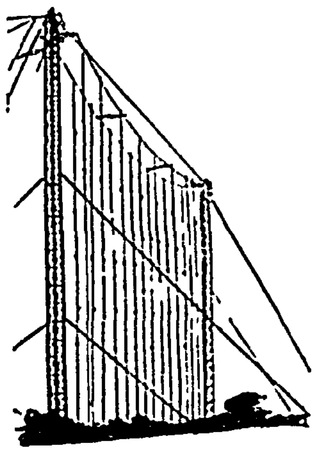
There are many kinds of deafness, and many kinds of hearing aid, from the simple ear-trumpet to an elaborate mechanism which carries sound to the internal ear through the bones of the skull. One very common kind works on much the same principle as the telephone There is a little microphone which can be worn attached to the belt or the pocket. An electric current from a small portable battery flows through this microphone, and when somebody speaks near it the vibrations cause fluctuations in the electric current Attached to the ear is a tiny receiver, connected by wires to the microphone, and the amplified sound from this receiver passes through a little tube

directly to the ear-drum, which thus receives a much greater volume of sound than it otherwise would

SOUND BY RADIO[1]

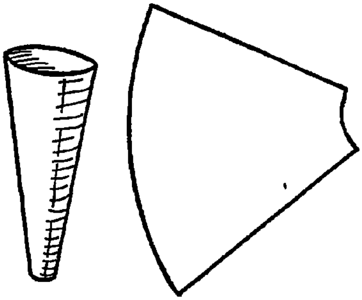
The beginning and end of a radio circuit are much the same as that of a telephone, but the middle is quite different

The microphone may be a simple carbon-grain microphone like that in the telephone, but more often it works rather differently, though its function is exactly the same, it picks up sound vibrations from the air and translates them into 'electrical vibrations' or fluctuations of an electric current Now a special kind of electric current, known as a high-frequency oscillatory current, is capable of throwing out wireless waves from a high transmitting aerial through the air in all directions If the 'electrical vibrations' are passed on to such a current the wireless waves will in their turn carry the fluctuations corresponding to the original sound waves Exactly how this is done is far too complicated a story for this book, but it is now possible to send wireless waves through space for thousands of miles, they will even travel right round the earth At one time this was thought to be an impossibility as the earth is curved and wireless waves travel in straight lines But it seems that those that travel upwards are reflected down again by an electrical layer that extends round the earth So wireless waves travel fairly close to the earth They can be picked up by a receiving aerial, and in the wireless receiver turned back again into ordinary electrical vibrations, these, in their turn, act on the diaphragm making it vibrate and give off sound waves into the air, as in the case of the telephone receiver



It takes about one-seventh of a second for a wireless message to travel right round the earth

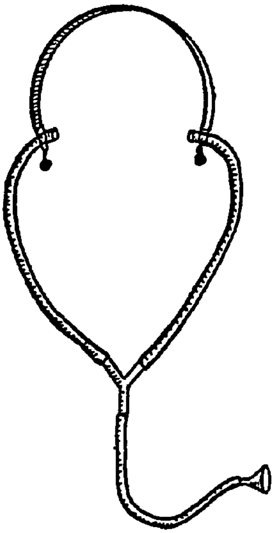
[1] This is described more fully in *The Current We Use*



Things to Do

1. Make a home-made megaphone from a sheet of thin card-board cut as shown in the diagram Pin or glue the edges together, and invent some kind of handle to hold it easily. Notice when you are using it that you feel as if you have to put rather more " effort " into your voice, this is because the air inside the trumpet is, to some extent, forming an extra resonator acting with the cavities of the mouth and throat, the speaker is, in fact, producing a greater volume of sound as well as directing it the way he wants it to go

2 Try some experiments using your home-made megaphone as an ear-trumpet



3. Make a home-made stethoscope This is the instrument used by a doctor when he wants to " listen in " to your chest It works on the same principle as a speaking-tube You need a little plastic funnel for one end (this costs 1d or 2d) some rubber tubing, and a glass Y-tube You can see from the diagrams how the tubes are fitted together You can arrange a piece of stiff wire or an old headphone holder to fit over your head and hold the ends of the two arms of the rubber tubing into your ears The funnel goes into the third arm You can use your stethoscope to listen to people's heartbeats and their breathing.

4 Ask your teacher if it is possible for your class to visit the local telephone exchange If this is not an automatic one try to find out how the operator knows when there is a call, how she puts a caller in communication with the person called, how large a district is served by the exchange, and how long-distance connections are made

NOW I KNOW

Here are some of the important facts and principles you have met in this book *The numbers in brackets refer to pages*

Sound is caused by something vibrating (3)

If the vibrations are simple and regular the sound is a musical note (6–8)

If they are complex and irregular the sound is a noise (6–8)

Low notes are caused by slow vibrations, higher notes by faster vibrations The faster the vibrations the higher the note (9–16)

With notes from stretched strings the pitch depends on the length, the weight, and the tension of the string The longer, the heavier and the looser the string, the lower the note The shorter, the lighter, and the tighter the string, the higher the note (17–20)

With notes from pipes, the longer the air column the lower the note (24–26)

Musical notes are seldom pure frequencies, they are accompanied by one or more overtones The overtones give the " quality " to the notes of a particular instrument (27, 28, 30–32)

Sound travels through air at a speed of about 1,100 feet per second (39–40)

Sound cannot travel through a vacuum (40–41)

Sound travels through water four times as fast as through air, and through some kinds of wood and iron fourteen or fifteen times faster (45–47)

Sound vibrations can be turned into " electrical vibrations " and sent long distances by telephone, and even longer distances by radio (69–71)